ELECTRICAL MEASUREMENTS *and* METER TESTING *in the* POWER STATION

WESTON
ELECTRICAL INSTRUMENT
CORPORATION

Engineering and Operating Suggestions for the Standardizing and Electrical Laboratories of the Public Utility

Dedicated to the Advancement of
the Electrical Laboratory of
the Public Utility

By

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Consulting Electrical Engineer

In Co-operation
With the Engineering Staff
of the

WESTON
Electrical Instrument Corporation
Newark, New Jersey

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FOREWORD

It is the established policy of the Weston Electrical Instrument Corporation to endeavor to render maximum service to purchasers of its products. In the broadest interpretation, such a policy consists of interest in the use of the product after sales have been consummated.

This book is one of a number that have been prepared with the sole object of assisting owners of Weston Instruments to use and care for their instruments to best advantage. It has been prepared under our supervision by an author well versed in the subject and it pertains particularly to the use of instruments in the Central Station Laboratory and in the field.

Theoretically, the functions of all Central Station Laboratories are much the same, but in practice, depending upon the size of the operating companies and the character of their loads, the laboratory and field work varies.

It is hoped that the reader will appreciate the difficulty of writing a book for an industry containing such a diversity of conditions and employing engineers of widely varying experience.

We have earnestly endeavored to make this work of great value to laboratory executives and to laboratory engineers and it is hoped that any of these gentlemen will feel free at any time to consult us with regard to suggestions or advice regarding any of these laboratory problems, since close co-operation of this nature is essential for the advancement of the art of electrical measurements, and any hesitancy with regard to correspondence of this nature would defeat the desire of this company to render a service in which it takes an unusual interest.

WESTON ELECTRICAL INSTRUMENT CORPORATION

NEWARK, N. J.

INTRODUCTION

The electrical or standardizing laboratory of the Public Utility is an important factor in the central station industry, and executives, as well as engineers, are devoting considerable time and thought to its development.

The laboratory is the watchdog of the entire system, serving all departments of the company. The operating department depends upon the laboratory for testing and inspecting its power producing equipment and for the calibration of indicating, integrating and recording meters; the purchasing department for the quality of materials and apparatus purchased; the new business department for assistance in determining the requirements of new customers or for extensions called for by old customers, while the accounting department depends upon the laboratory for its receipts thru accurate meter readings.

In general, it may be stated that the laboratory performs two functions, that of a standardizing department and of a general service department. In the smaller laboratories, these services are usually rendered by the same engineers, but in the larger companies these two classes of work are entirely separate.

Regardless of size, the basis of the entire laboratory work depends upon accurate and reliable electrical measuring instruments. They form the foundation of any electrical laboratory equipment.

Since 1888, the Weston Electrical Instrument Corporation has led in the art of electrical measurement. Its indicating instruments are extensively used in practically all laboratories throughout the United States and in the majority of laboratories throughout the world. The name "WESTON" always signifies a high-grade instrument and indicates a service that means much to the electrical industry.

CONTENTS

Chapter I

LABORATORY ENGINEERING AS A PROFESSION

There are few positions in the electrical industry that offer more opportunities than the electrical laboratory. It is in the laboratory that the methods and application of testing are actually carried out. Laboratory engineering is extremely fascinating and its field is open for both the college graduate and the man with practical experience.

The duties of the laboratory engineer depend upon the size of the company and how extensively the laboratory has been developed. The large companies maintain extensive laboratories containing several departments whose functions cover a broad field. In the smaller laboratories the field is not so extensive, but the engineer is more dependent upon his own resources and has an excellent opportunity for developing his own methods and ideas. The industry requires men of responsibility and good education in the fundamentals of electrical engineering. Meters must read accurately and electricity must be generated and distributed continuously and economically day in and day out. This means service and it takes carefully trained men to keep this service at 100%, where it belongs. The services performed by the laboratory are therefore of extreme value, both to the company itself and to the public. Without adequate laboratories, the growth of the central station industry would be greatly retarded.

As the central station business is non-competitive, laboratory engineers are in a position to co-operate and interchange ideas and methods. The more this is done, the better it will be for the industry. The profession offers many opportunities but it depends entirely upon the engineer himself to make the most of these opportunities.

Chapter II

THE CENTRAL STATION STANDARDIZING AND ELECTRICAL LABORATORY

The facilities and personnel of the laboratory department depend upon the number of customers served by the company. The size, however, does not affect the importance of this department, as the problem is the same for all companies, large or small. As a matter of fact, there are far more small laboratories employing from one to five men than there are large laboratories

employing from fifty to two hundred men. The larger companies maintain a special laboratory department known as the "Meter" department, whose principal duties are checking the customers' meters and is separate from the electrical laboratory. Very often in these companies the electrical testing laboratory is under a different but co-operating head. With the smaller companies, the meter department and laboratory are all under one head and use practically the same facilities. In order to properly carry out the work of the laboratory department, it is very essential that the proper facilities should be available and that the testing program be carried out with reliable and accurate electrical measuring instruments.

The Location

The location of the laboratory will depend upon circumstances, a separate building or at least a separate floor being much preferred for the large companies. For the smaller companies this is not necessary, and the laboratory may be located in some convenient place in the power house or office building. In any event, it should be located near the center of the company's activities. No fixed rule can be given for the amount of space required, as this depends upon the nature of the work done in the laboratory and how much work is to be undertaken. As a general rule, one or two good-sized rooms will answer for the average laboratory.

There are several important items to consider in building or in locating a laboratory, complete details of which are beyond the scope of this book. However, it might be well to mention briefly a few items which should be given consideration.

Vibration

Vibration should be avoided, and for this reason care must be exercised when the department is to be located in a power-house or sub-station where rotating machinery is used. When slight vibration is present, we suggest mounting tables and benches on small felt pads. In some cases it may also be necessary to have instruments rest on these pads, which will take up a small amount of vibration. When precision measurements are made using sensitive galvanometers, it is necessary to avoid vibration, and when vibration is present special means must be provided, such as suspending galvanometers from the walls or ceiling by means of springs.

To lessen the difficulties of vibration, the Weston Electrical Instrument Corp. has developed a very sensitive galvanometer, known as Model 440. (See Fig. 62.) This galvanometer is of the portable type, being especially suited for tests or calibrations using the "null" method, and it may be used in places where vibration would make the reflecting type of galvanometer useless.

Proper Lighting

Proper lighting is also essential, as shadows should be avoided where instruments are being read. A uniform distribution of light over the entire laboratory is far better than individual drop lights. Either the indirect or semi-indirect method of lighting is strongly recommended and it will be found much easier to read instruments under these lighting conditions. Obtain as much daylight as possible in the laboratory and locate the test tables near windows.

Painting

Painting of the laboratory should be in some light color, preferably a flat white, to obtain uniform lighting. A light color also tends to make it more attractive in appearance. It is suggested that the base walls be painted some dark color for a distance of from one to three feet from the floor. This will make the appearance of the laboratory much better and will reduce the amount of care necessary when cleaning.

Other items such as proper ventilation and fire protection should also be considered. It is desirable to locate the laboratory in as clean a place as possible so as to avoid unnecessary dirt. Either a hardwood or a cement floor will be found preferable. Cement should be painted to avoid the possibility of forming dust as it wears.

Heating

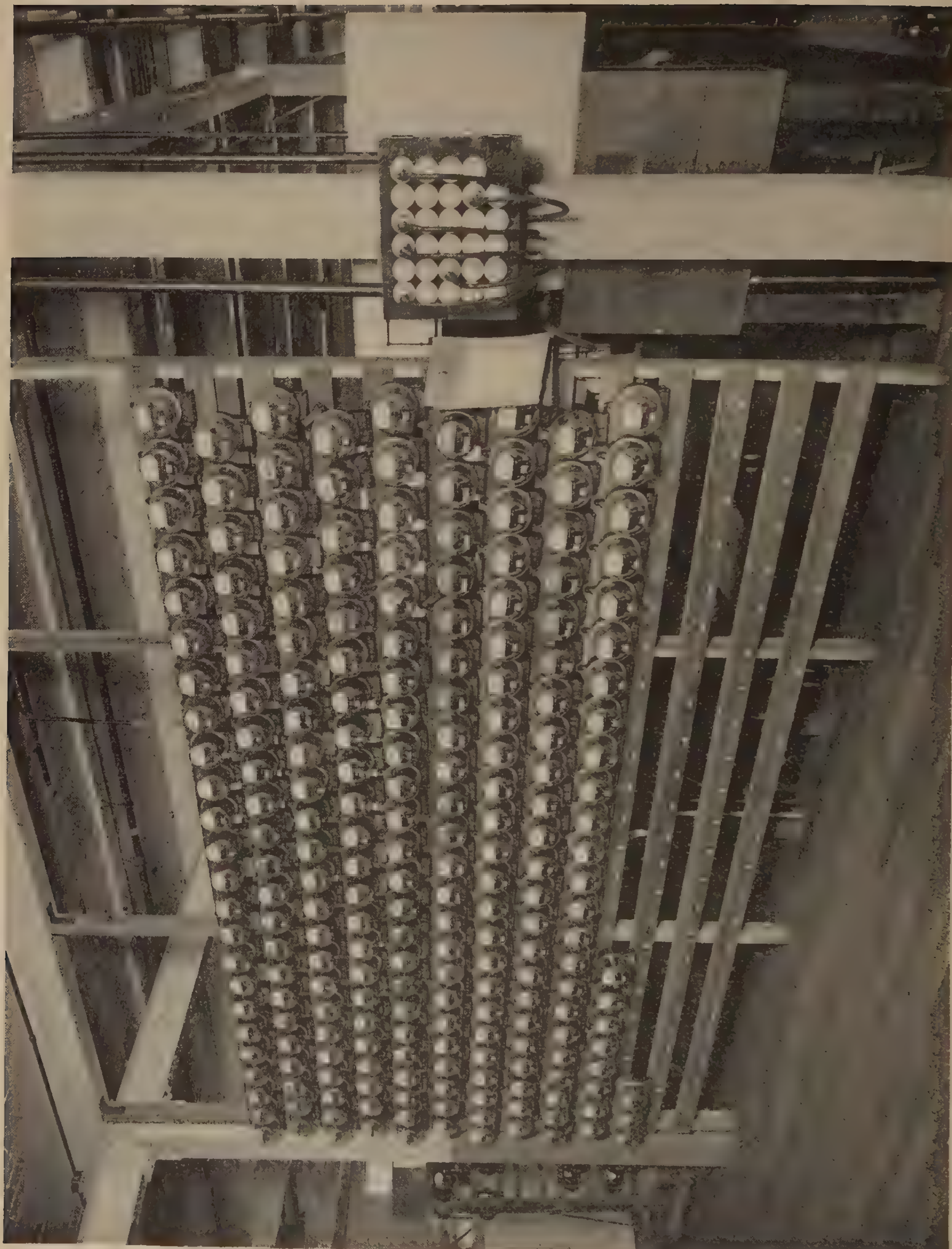
Heating the laboratory is practically no different than that of other buildings, but it should be uniform and great extremes of temperature should not exist. It is far better to keep scientific instruments under even temperature and not allow them to be exposed to extreme differences in temperature. The extremely cold conditions experienced in some buildings over Sundays and holidays during the winter months in the northern part of the country should be avoided.

Cleaning

In the course of business in the laboratory, a routine schedule should be maintained for looking out for its care, cleaning, etc., as dust and dirt are enemies of instruments of any nature.

Storing Instruments

It is very important that instruments should be properly kept when not in use, hence regular instrument cabinets should be provided in every laboratory. Each instrument should have its designated place and the cabinets should be provided with glass doors so that the instruments may be visible, yet free from dirt and dust. The bottoms of the shelves should be lined with felt. Figure 1 shows a good lay-out for a laboratory. At the right in the back-



ground is shown an instrument cabinet with glass doors, containing a numbered compartment for each instrument.

Facilities should also be available for storing equipment which is to be used in the future, and also for equipment or apparatus awaiting test or shipment.

It is preferable to keep watt-hour meters on wooden or metal racks. Figure 2 shows a rack used in a large laboratory. Metal racks are to be preferred on account of durability and are simple to construct of standard size angle iron. Figure 3 shows a portable rack used for transporting meters about the laboratory.

The working tables or benches should provide ample space for the instruments. A surface of 60″ x 30″ will be found convenient.

Laboratory Extensions

In laying out any laboratory it is wise to provide for extensions or additions to meet the natural growth of the company's business or possible consolidations.

Special Room for Primary Standards

When laboratories maintain primary standards, it is advisable to keep them in a separate room away from the activities of the main laboratory. This will keep the standardizing equipment away from the general run of laboratory work, and the engineers will be able to perform their services better under these conditions. Such a room should contain the potentiometer together with its auxiliary equipment and a special place for the Weston cadmium cells which form the basic standard of potential.

Weston secondary standards may be used in the regular laboratory on special tables, but we strongly recommend a special room whenever space permits. However, in the following paragraphs are described these high grade instruments, which can be placed at whatever points may seem best adapted.

Chapter III

DESIGNING AND EQUIPPING A LABORATORY

One of the most essential items in designing and equipping the electrical laboratory is to so arrange facilities as to reduce to a minimum the amount of labor necessary for its operation. The design should be as simple as possible and the amount of equipment used should be reduced to a minimum but selected on the basis of quality. As much of the equipment as possible should

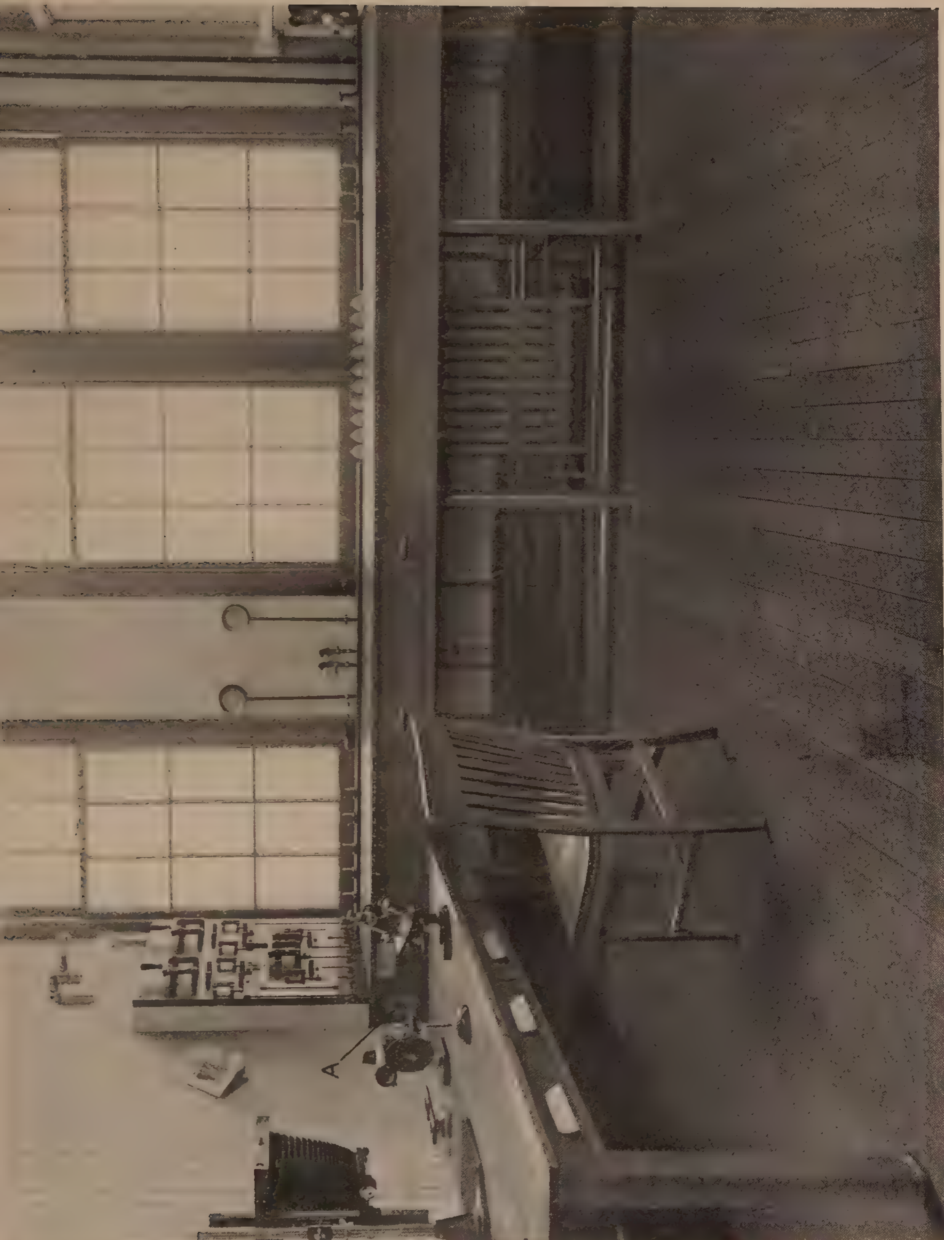


Fig. 4. Research Laboratory

be permanently installed, and operations of a routine nature should be standardized. The arrangement of the facilities should be such that confusion will be reduced to a minimum. In other words, avoid transporting heavy equipment across the entire laboratory by having facilities for handling it near the elevator or other entrance. Keep the main aisles away from tables or benches upon which accurate measurements are to be made. Sufficient room should be allowed between the various tables or benches, so as to avoid interference between workers.

Switchboards, storage batteries, transformers, etc., should not be located too far away from the laboratory, as otherwise the connections become excessively long and the cost is thereby increased.

It is well to locate the apparatus on tables as shown in Figure 1, and to have a table or bench for each particular class of measurement, such as volts, amperes, watts, etc. Several tables or benches should be provided for work of a general or special nature. Special tables or benches for checking watt-hour meters and rotating standards should also be reserved.

In some cases, long benches may be better adapted for the requirements than separate tables, In either case, a hardwood or slate top is preferable.

In describing laboratory facilities and in the coming chapters the words calibration, checking and testing are used in the following ways: Calibration to mean the actual marking of the instrument scales. Checking to mean the comparison of readings of one instrument with another. Testing, as a general term covering the finding of faults or determining the condition of any apparatus or instrument itself. This suggestion is made with the idea of reducing the confusion that would exist in using the word calibration to cover all terms.

Research Laboratory

If any research work is to be undertaken, it is advisable to have this done in a separate room, as shown in Figure 4. Such a room should be supplied with a switchboard or other means of connection to the laboratory system. In this particular laboratory (Fig. 4), a wooden bench is used and on the rear of this bench will be seen a slate strip 2″ wide by 1½″ thick, running practically the entire length. Upon this slate are mounted the binding posts for test circuits. The large binding posts shown at each end of this slate strip are connected together, so as to avoid running wires on the surface of the bench from one end to the other. This laboratory should be supplied with a small panel similar to the one shown in Figure 5. The panel may be connected to the main laboratory switchboard through a transfer panel, as shown in Figure 6. In this way the supply of electricity may be changed from one source to another without the use of any temporary connections. The panel is so

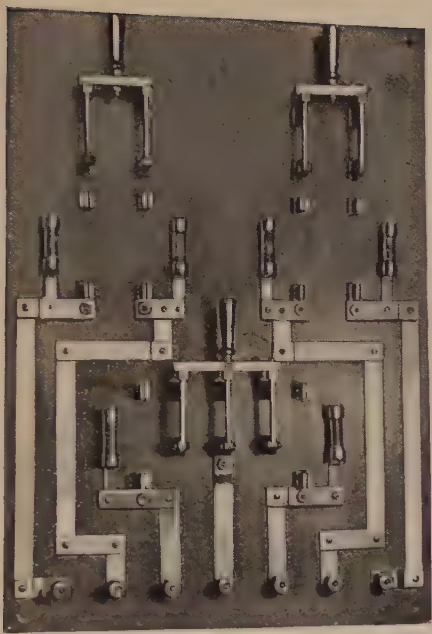


Fig. 5. Panel Board for Research Laboratory

arranged that it may be fused in any capacity up to 100 amperes, as the fuse terminals are connected in multiple. The binding posts connecting the switches are shown at the bottom of the panel. This particular panel has been used successfully, but is mentioned as a suggestion only to show what can be done to reduce the amount of labor and thus make the facilities of the research laboratory of more value.

In Figure 4, on the left-hand end of the bench, will be seen a small momentary contact push button marked "A." This button can be arranged for the remote control of load rheostats. When heavy currents are handled from the research laboratory, this method will be found convenient.

Controlling Switchboards

In order to properly distribute electric current about the laboratory, a controlling switchboard located at some convenient point should be provided. It is impossible to recommend any particular design for this switchboard without knowing the requirements of the laboratory. However, the board should be simple and located as near the center of activities as possible. This main switchboard should contain switches for controlling the various circuits, together with the necessary protecting devices, measuring instruments, etc.

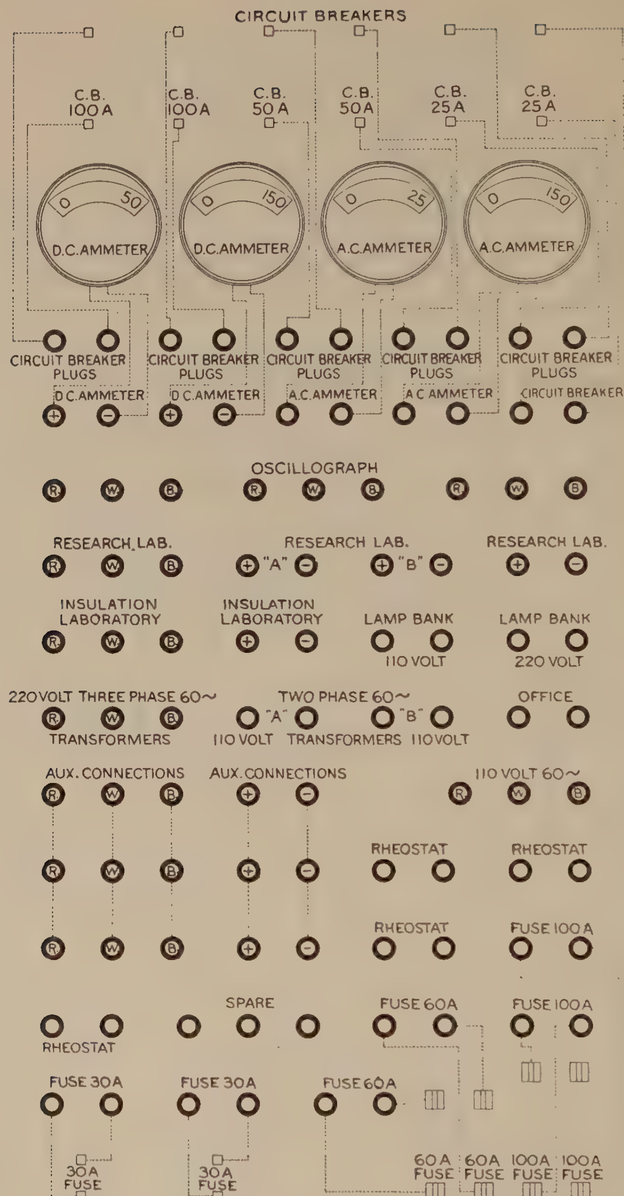


Fig. 6. Switchboard Transfer Panel

In Figure 6 is shown diagrammatically a convenient type of switchboard for laboratory use which may be termed a "transfer" panel. Such a panel acts

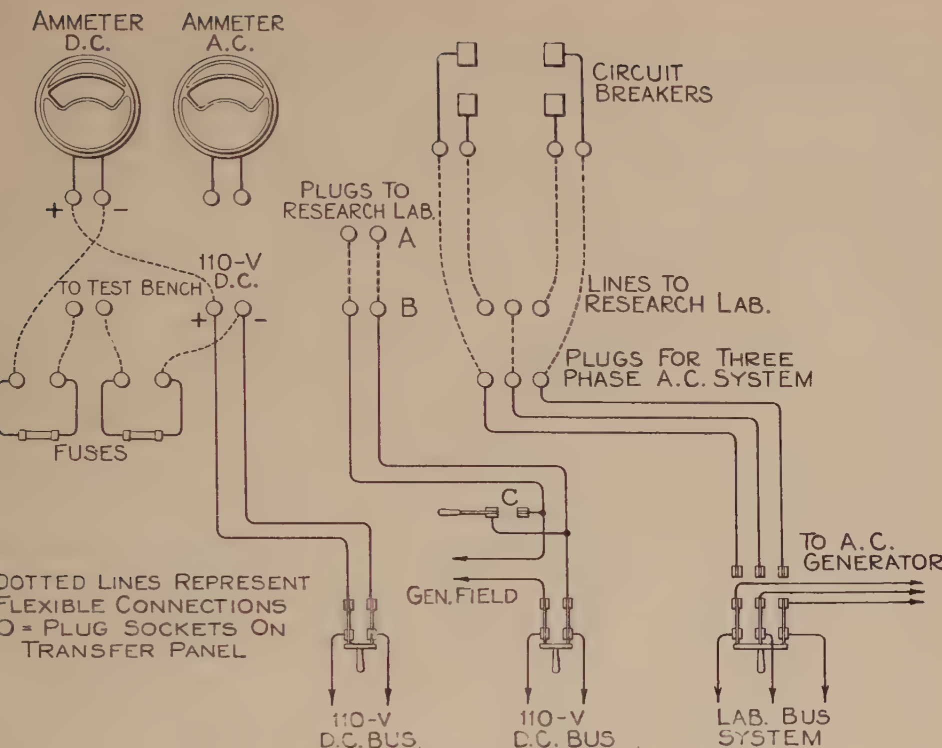


Fig. 7. Use of Transfer Panel

as a connecting link between the main switchboard and the various test tables or benches about the laboratory. By means of this panel, any circuits may be connected together and have the proper fuse or circuit breaker protection. Switchboard instruments are desirable so that the amount of current used on any particular circuit may be determined. By means of this panel, it is possible to put the control of a motor generator set or generator directly on some particular test bench or in the research laboratory. This may be connected as shown diagrammatically in Figure 7. In this diagram is shown an A. C. generator connected through the transfer panel to a research laboratory. Proper protection for the generator is given by the circuit breakers on the transfer panel. The field control of this generator may be obtained in the research laboratory by properly connecting the plugs shown at "A" and "B" when switch "C" on the main switchboard is left open. On this same figure is shown a 110-volt direct current supply connected to some particular test bench through the transfer panel. In this case the circuit is protected by

fuses, as shown, and the amount of current taken measured on the ammeter. The dotted lines in the Figure represent the connections between the plugs using the flexible connectors shown in Figure 8.

Auxiliary connections are shown on the transfer panel which allow a particular supply of current to be connected to two different sources. The scheme of this panel may be carried further, by using recording instruments,

Fig. 8. Flexible Connectors Used for Transfer Panel

time switches, etc., in connection with the various laboratory circuits. Furthermore, the oscilliograph can be permanently connected with this panel, which will make its use available in any part of the laboratory. The illustration given covers important items, but it may be varied in any way to suit the requirements of the particular laboratory. Such a panel is very simple to construct and for those who wish to make up their own equipment a few details of the construction are given. In Figure 9 is shown a working

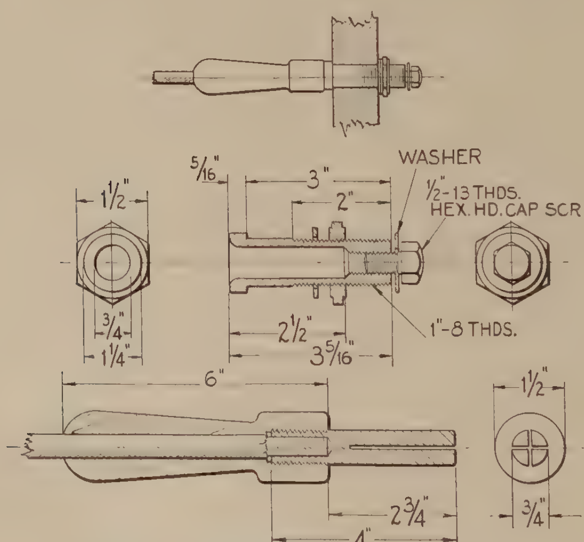
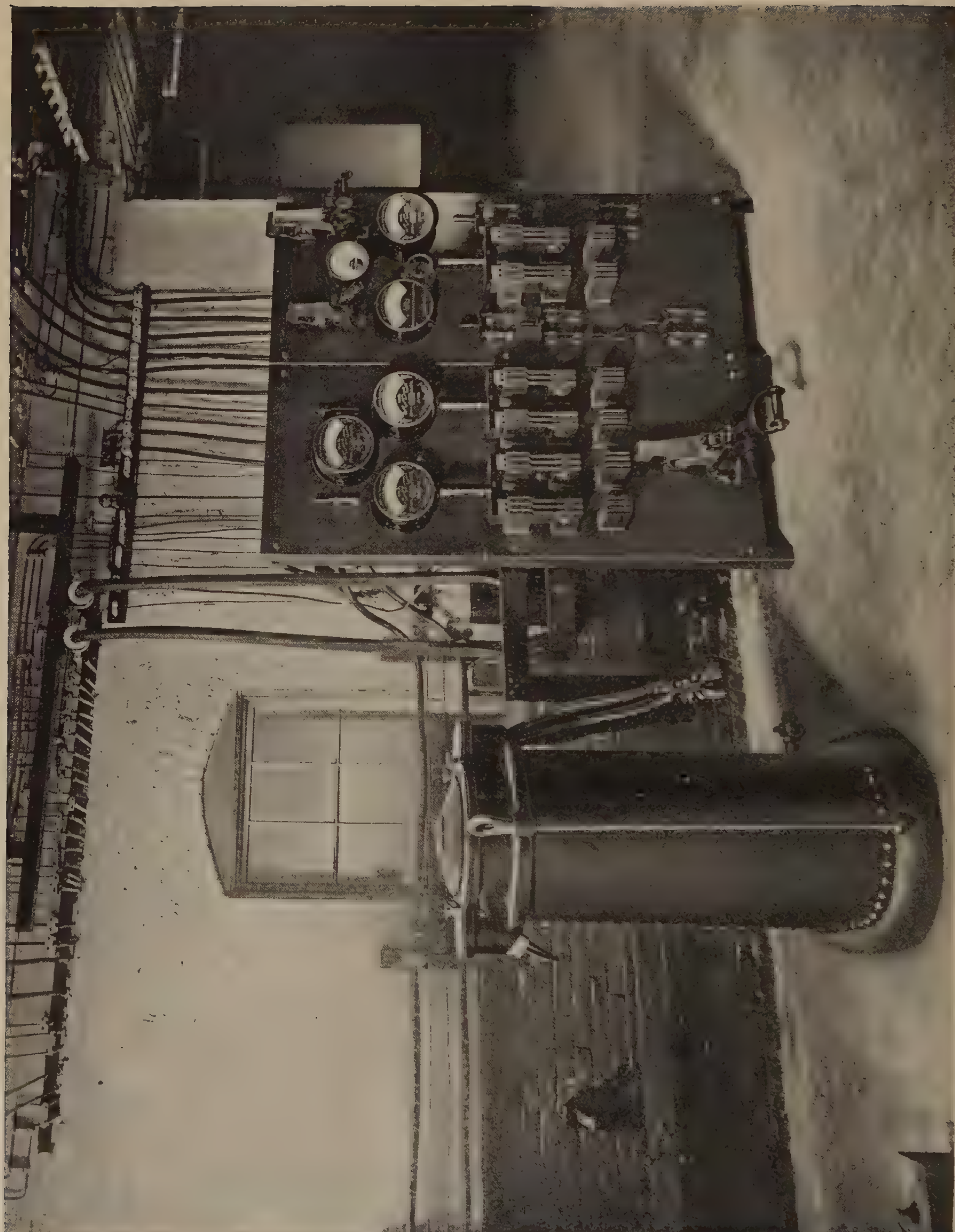


Fig. 9. Construction of Panel Connector and Receptacle

Fig. 10. Transfer Panels In Use In Laboratory



drawing of the plugs and their receptacles. A pair of finished plugs is shown in Figure 8. These plugs have a capacity of 100 amperes and have been found to give entire satisfaction. To reach various connections on the panel different lengths of cord should be available. These plugs are shown in use on the switchboard in Figure 1 and are used for connecting together various benches about the standardizing laboratory. It is well to systematize the wiring in the laboratory, especially in connection with the transfer panel. In carrying out this scheme, the left-hand wires on the D. C. circuits may be positive and the right-hand negative. The different phases on a three-phase system are marked "R," "W" and "B." These letters stand for "red," "white" and "blue" wires. The wires themselves are not actually colored, but their position indicates the color when going from left to right. Two-phase systems are simply marked phase "A" and phase "B" and are often treated like the D. C. circuits. Such a board is extremely flexible, allowing changes to be made quickly to meet varying conditions in a large laboratory. If a color scheme is not desired the use of the letters "A," "B," "C" or figures 1, 2, 3 may be used.

In Figure 10 is shown, in the background, a large transfer board containing five panels. This board is used for connecting all departments of the entire laboratory and for distributing electricity under control of the large switchboard shown at the right of the picture.

In Figure 11 is shown a low voltage high current switchboard, for use in electro-chemical or electro-metallurgical research work. To economize on copper, double throw switches are used on this work, so that either alternating or direct current may be supplied to the laboratory.

For small laboratories, a small switchboard, as shown in Figure 12, will be found extremely convenient. Even in large laboratories, a bench fitted up with the arrangement shown will be found very useful. It may be fitted for either alternating or direct current, or both. The board connects to the supply system through a main switch. This switch can be double throw and thus used for both direct and alternating current by supplying the proper measuring instruments as desired. By means of the every-day attachment plugs, the various connections are made to the work in hand on the test bench. The diagram is very well marked and needs little explanation. A switchboard ammeter and voltmeter are used for general work, but plugs are provided so that precision instruments may be connected into the circuit if desired. Furthermore, potential and current plugs are available so that a wattmeter may be used. The resistance or lamp bank which is shown is connected in parallel with two plugs. These plugs are for use with external resistances such as a heater or toaster, so that additional current may be available for test purposes. If no resistance at all is required, the resistance cut-out switch may be used.

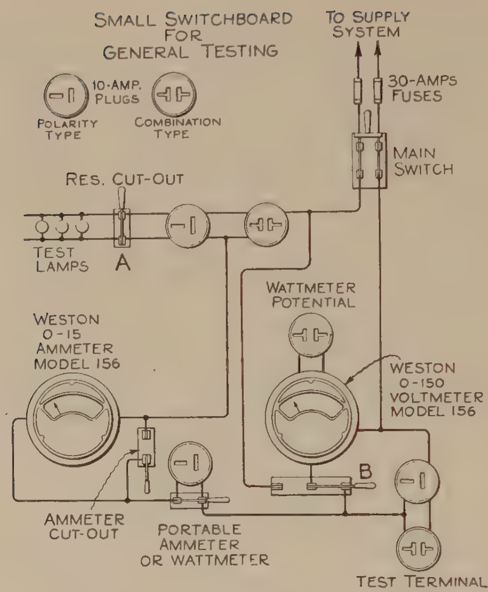


Fig. 12. Attachment Plug Switchboard for General Testing

Two types of plugs are shown, as in some cases it is desirable to always have the same polarity. The double throw switch under the voltmeter may be used to connect the voltmeter or wattmeter potential circuit directly to the line or through the resistance, if same is in circuit.

Current Supply

The supply of electricity for the laboratory will depend upon that furnished by the company which it serves. The important point is good regulation, as the laboratory requires a steadier potential than any of the central station customers. If the laboratory is located close to the generating plant, good regulation is often obtained, but in the majority of cases the regulation of the system is not sufficient for accurate work in the laboratory. The most satisfactory supply for any laboratory is from a storage battery. This can be used direct or through a motor generator set when alternating currents are required. The batteries should be located in a separate room or compartment, which should be thoroughly ventilated and carefully protected with acid-proof paint. Acid fumes are deadly enemies to instruments of any nature and for this reason must be avoided in the laboratory or instrument room. In some

cases, where high currents at low voltages are necessary, a few individual portable storage cells may be used mounted under the table or bench, as the case may be.

Wiring and Installation

There is no excuse for poor wiring or a slip-shod installation in the laboratory. Here is an opportunity to show what good design and workmanship can produce. A laboratory properly designed and constructed is an impressive sight, especially to the layman. The inspection of a good laboratory makes an impression on the public and adds confidence to the customer's good-will.

As much of the wiring as possible should be permanent and when temporary wiring is required it should be removed directly after use. This is important, as much temporary work is necessary in any laboratory.

The National Electric Code should be followed as closely as possible. However, it does not cover all cases and cannot always be followed exactly in a laboratory. For this reason the designer must use his own judgment, and eliminate as far as possible any life or fire hazard. The use of iron conduits is strongly recommended and makes a permanent installation.

Sufficient copper should be used to allow for extensions and to avoid excessive "drop" in potentials. All wiring connections should be clean and carefully soldered.

It is suggested that no knife switch having a capacity of less than 60 amperes be used unless it has three or more poles. A small switch, especially if single pole, has very little mechanical strength.

It will be found a great convenience in operating a laboratory to have the wiring systematized. For example, if in all direct current wiring, contacts, switches, binding posts, etc., the polarity is always the same, as already suggested, it will be of great assistance. In such a case the left-hand binding post or other terminal may be + and the right-hand —. In three-phase work, keep the same relative position between all wires, by starting at the left and call each wire the "Red," "White" or "Blue" conductor. In such a system the middle pole is always the same or "White" wire. A similar method can be used for two-phase systems.

Diagrams of all connections should be available, as shown in Figure 13. In this case each circuit has a separate number which appears on all apparatus connected, such as a generator, measuring instrument, switch, fuse, etc. It is well to keep these diagrams in loose leaf form to take care of changes and additions. If more than one diagram book is used, one should be reserved for the tracings from which other copies may be obtained. If possible, a large diagram of all connections should be mounted in the laboratory, where it may be referred to by all.

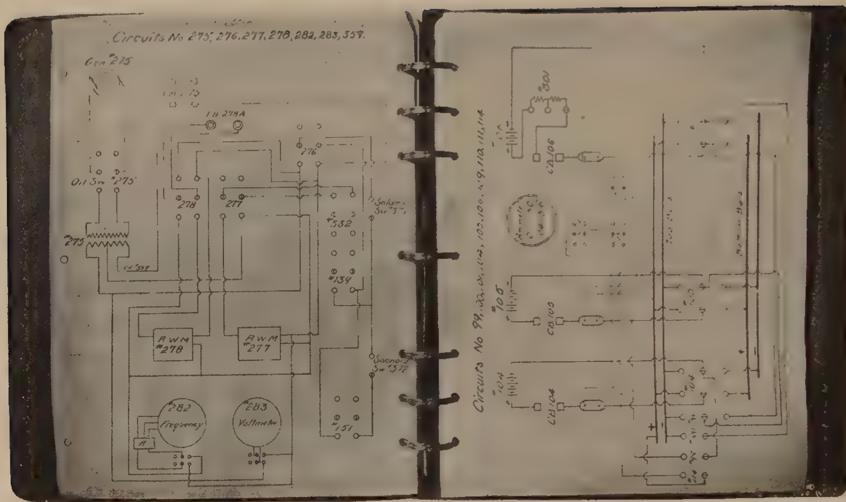


Fig. 13. Loose Leaf Note Book for Diagrams

Artificial Loads

In any laboratory, variable resistances or artificial loads are necessary. These resistances must have uniform control and be of ample current carrying capacity to keep within proper temperature limits. This is an important subject and should not be overlooked in any laboratory.

There are several methods of obtaining the artificial loads and resistances, depending upon the nature of the work. For laboratory work the most convenient type is the "slide wire," as shown in Figure 14. This form is very uniform and may be obtained in various capacities from a few ohms to several thousand ohms. They measure from 8 to 20 inches in length, and are furnished for wall or table mounting in either a horizontal or vertical position. These rheostats may also be obtained for switchboard mounting. They are also supplied with double "sliders" and in banks of two and three tubes. In most cases the larger or 20″ tubes are to be preferred on account of their better regulation. In some cases for alternating current work the use of stone blocks instead of steel tubes is better, as hysteresis losses and the inductance are less. While these rheostats are very convenient, they are limited to a maximum current capacity of about 25 amperes continuously.

Figure 15 shows a suggested form of wood cover for use in protecting a slide wire rheostat.

For heavier currents the use of carbon rheostats is recommended. They are simple to construct and will carry heavy overloads for a short time.

Fig. 14. Slide Wire Rheostat

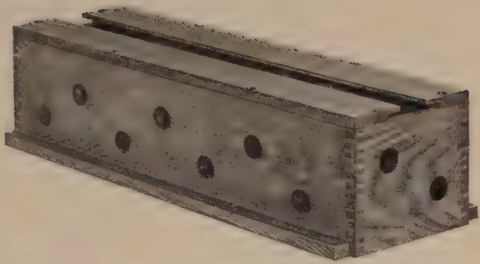


Fig. 15. Wooden Guard for Protecting Slide Wire Rheostat

The conventional lamp bank also provides a resistance, but is better adapted for a direct "load" than as a means of variable resistance. The use of carbon lamps will make a load suitable for the average laboratory for use on 110 and 220 volts.

For very heavy loads, water rheostats are best adapted and the conventional "barrel" type has given good satisfaction.

Other forms of rheostats may be used such as iron wire mounted on a wood or iron frame. Such rheostats are, however, subject to sudden changes in resistance if exposed to drafts or sudden changes in temperature.

The regular type of field rheostat may be used provided sufficient steps are available.

In general, it may be said that rheostats or other loading devices are available to meet the requirements of any laboratory. In Figure 16 are shown two types of resistance units that may be used for fixed values or in the construction of rheostats. With present-day facilities, rheostats or artificial loads may be made "remote control" if necessary.

General Testing

In any laboratory, tests are often required of miscellaneous apparatus, such as motors, appliances, etc., and a special table or bench should be provided for this purpose. Some very simple method will answer, as already suggested in Figure 12. In a very small laboratory, such a scheme is all that is required for any testing and is very inexpensive to construct. It is also very convenient for general testing in a large laboratory, especially if connected to a "transfer" panel. With such a test board and a Weston Voltmeter and Ammeter, a great many tests may be made.

Repairs

Repairs to equipment or to outside apparatus will be required from time to time and facilities for this work should be available. The lighter work can be

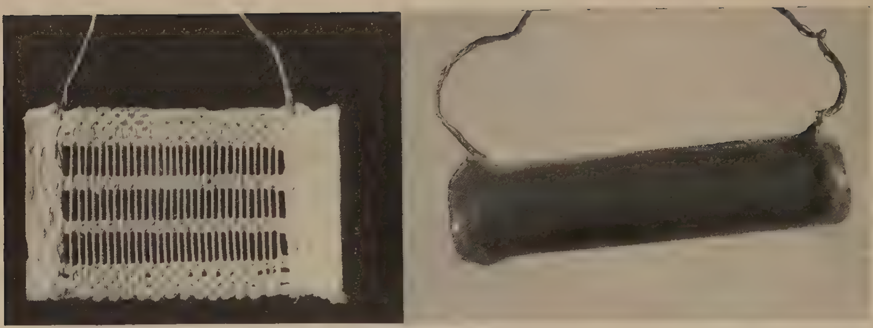


Fig. 16. Resistance Units for Making Rheostats

done in the laboratory, but any heavy repairs should be carried on in a separate room away from the instruments. A small work bench or individual shop will be of great assistance.

For the larger companies, a special shop is recommended for repairing instruments and meters, which should be kept as free from dirt as possible. With the smaller companies it is perhaps better to return instruments that need repairs to the makers.

The essential points in repair work may be summarized as follows:

Provide a proper location for the work.

Provide proper tools and a place for each tool.

Keep a stock of necessary repair parts.

Keep the shop as clean as possible.

Allow only first-class repair men to use the facilities.

Keep everything in its proper place.

Direct Current Voltmeter Table

The problem in direct current voltmeter checking is to provide a *constant* voltage having any value from the minimum to the maximum scale value of the voltmeter under test. These variations must be under the uniform control of the operator and arranged so as to avoid any excessive increase above the maximum scale reading of the voltmeter.

As a rule, facilities for checking direct current voltmeters and ammeters are placed on the same bench or on adjacent tables, as shown in the background at the left of Figure 1. This arrangement brings the direct current checking in the same part of the laboratory, and provides facilities for checking wattmeters on direct current.

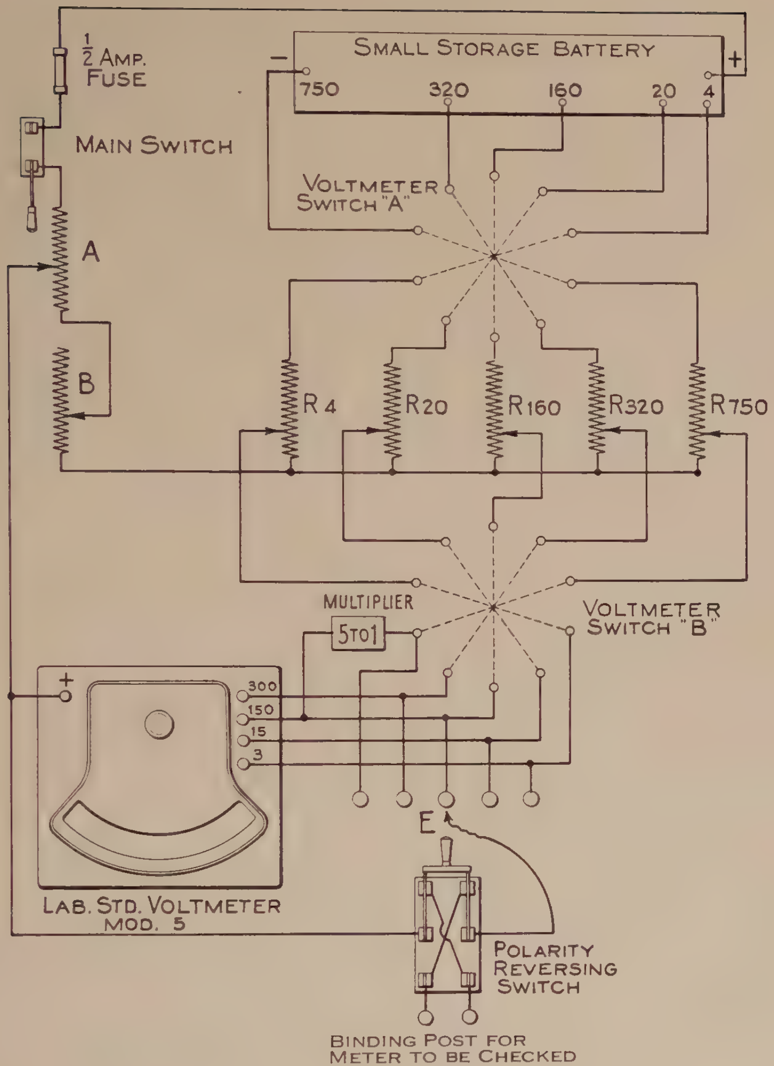


Fig. 17. D. C. Voltmeter Checking

A very satisfactory and practically foolproof connection for checking direct current voltmeters is shown in Figure 17. For this purpose a Weston Laboratory Standard Voltmeter, Model 5, having an accuracy of 1/10 of 1% is best adapted. Referring to the diagram, it will be seen that two voltmeter switches "A" and "B" are used for making the proper connections for voltage and for the proper instrument range. This makes it impossible to increase the voltage of any range far beyond its maximum. The voltmeter switch "A" selects the proper battery voltage, while voltmeter switch "B" connects switch "A" to the proper range of the standard voltmeter. Each of the five separate ranges has a rheostat of its own, while those shown at the left of the diagram "A" and "B" are common for all ranges. The reversing switch at the bottom of the diagram is for changing the polarity of the voltmeter or wattmeter under test.

At "E" is shown a flexible connection which is used for connecting the voltmeter under test to the proper scale of the standard voltmeter. One end of the flexible terminal is permanently connected to the double throw reversing switch. Its other end is provided with a flexible terminal "E," arranged so as to reach any one of the five test binding posts. This terminal must be connected to the binding post corresponding to the scale of the instrument under test.

In the above-mentioned diagram, the potentiometer method of control is used with slide wire rheostats for obtaining the proper resistances. All rheostats and switches should be so arranged as to be within easy reach of the operator and should be clearly marked. However, the slide wire rheostat should not be placed nearer than 10″ from the laboratory standard instrument. The arrangement suggested in Figure 18 will be found convenient. The two common rheostats used for the fine adjustments of voltage are placed at the front of the table at the left so that they may be regulated by the left hand of the operator. This leaves the right hand free for recording the readings. If the wiring is under the table, white lines may be drawn on the surface to show their location.

In order to compensate the Laboratory Standard for the earth's magnetism, it is preferable to have the tables placed lengthwise in a North and South position.

The arrangement described above may be used for testing any D. C. or dynamometer type portable or switchboard voltmeters on the market within the range of the Standard. Voltmeters of the induction type and for the highest accuracy, those of the movable iron type, however, must be calibrated and checked with alternating current. If other ranges are desired, proper scales may be substituted on the standard voltmeter.

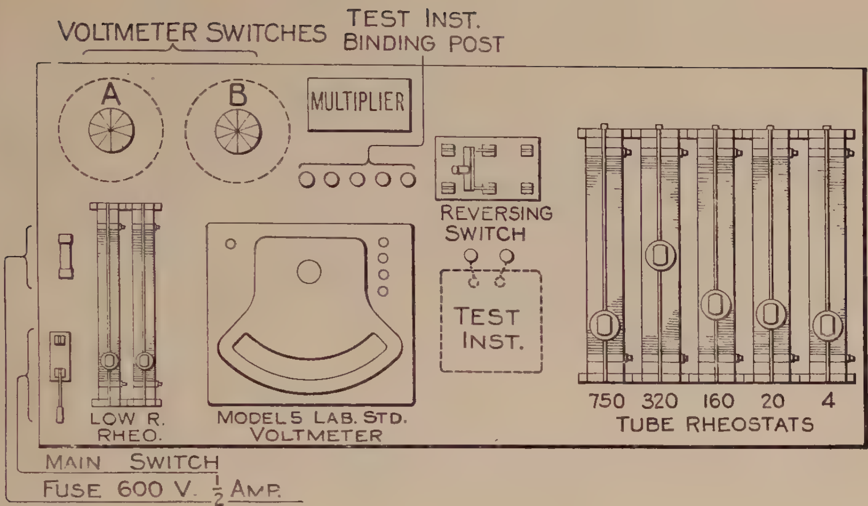


Fig. 18. Arrangement for Apparatus Shown in Fig. 17

Next to an accurate standard voltmeter in importance is a constant supply of current, preferably from a storage battery. One having a capacity of eight ampere hours is sufficient, or a large size "radio" battery may be used for checking D. C. voltmeters. If a 750-volt battery is used, it may be charged from a small 220-volt motor-generator, the battery being grouped as shown in Figure 19.

If it is desired to charge the high voltage storage battery from an existing laboratory circuit, it will be necessary to connect the cells in groups of series-parallel, as shown in Figure 19. In this Figure is shown a 750-volt battery arranged for charging from a 220-volt direct current circuit. The value of the variable resistance "X" depends upon the size of the battery. It should have sufficient range and capacity so that any single group or all cells may be charged at the same time.

The use of individual resistance for each group of batteries is not necessary in the case of these small cells, which only require occasional charging, and deliver extremely small currents for short periods of time.

In Figure 19 are shown the taps giving the proper voltage for voltmeter calibration or checking, shown complete in Figure 17. To compensate for losses in the rheostats, a slightly higher voltage is necessary than that of the instrument scale. This is the reason for using 4 volts for the 3-volt range, 20 volts for the 15-volt scale, etc.

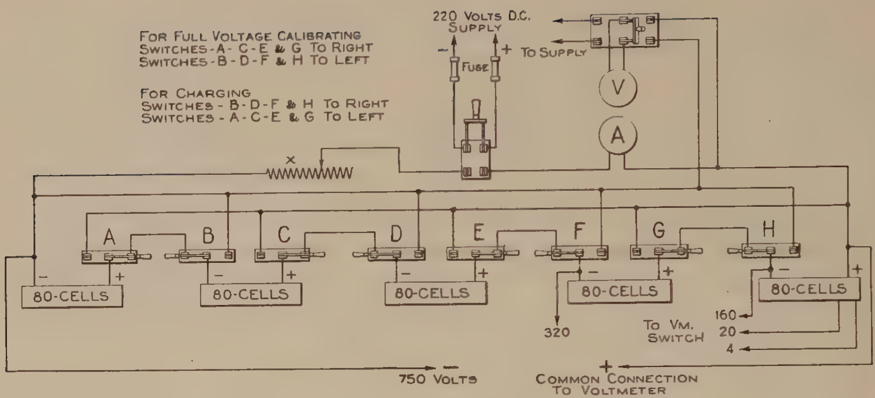


Fig. 19. Storage Battery Connections

The number of groups of cells for a 750-volt battery, with different charging voltages, are as follows:

Laboratory Supply Voltage	*No. of Groups*
550	2
220	5
110	10

If a storage battery is not available for voltages over 110, the use of a small motor-generator set, Figure 20, connected as shown in Figure 21, is recommended. A small fractional horse-power motor or large fan motor driven above speed will answer. The generator shown in Figure 20 is used for potentials up to 300 and was originally a 220-volt fan motor. The driving motor should be supplied with a steady voltage.

Referring to Figure 21, the main switch is shown at "A" and controls the driving motor "M" and the separately excited field of the generator "G." Many small 500-volt machines have four poles which may be connected in multiple for 110-volt field excitation. If the generator cannot be separately excited its field wires should be disconnected at points "M" and "N" and connected to its armature terminals through rheostat "Z." Switch "H" controls the voltmeter circuit. For checking instruments using the 750-volt scale of the standard voltmeter, switch "B" is in its left-hand position. This gives the maximum field strength for the generator. When switch "B" is in its right-hand position, the 300 and 150-volt scales may be used. When switch

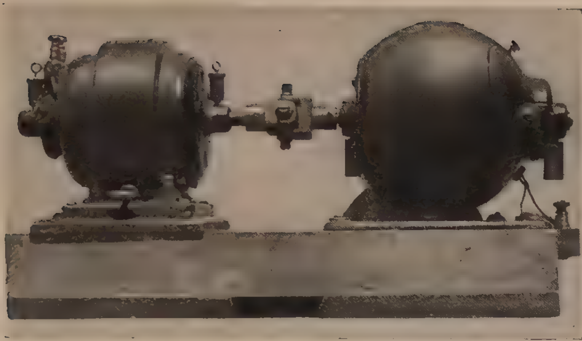


Fig. 20. Small Motor Generator Set

"C" is in its left-hand position, the 150-volt scale of the standard voltmeter is in circuit with the generator "G." Switch "C" in its right-hand position connects the generator "G" with the 300-volt scale of the standard voltmeter. The fixed resistances "E" and "F" are in the field circuit of the generator "G" and should have such a value as to keep the generator voltage from going above 300 when switch "C" is closed to the right and 150 volts when closed to the left.

Rheostats "X" and "Y" regulate the voltage of the instrument circuit, and rheostat "Z" controls the field current of the generator "G." Rheostat "D" regulates the speed of the driving motor "M."

There are many methods of connection and arrangement of facilities, but those mentioned above are as nearly foolproof as could be desired. The potentiometer method of voltage regulation will, however, be found more flexible than that with the use of series resistance in the instrument circuit. The slight extra cost for proper protection is good insurance against injury to expensive instruments and delays.

Order List of Material (Figs. 17 & 18)

To complete the test table as shown in Figure 18, and connected as shown in Figure 17, the following material will be required:

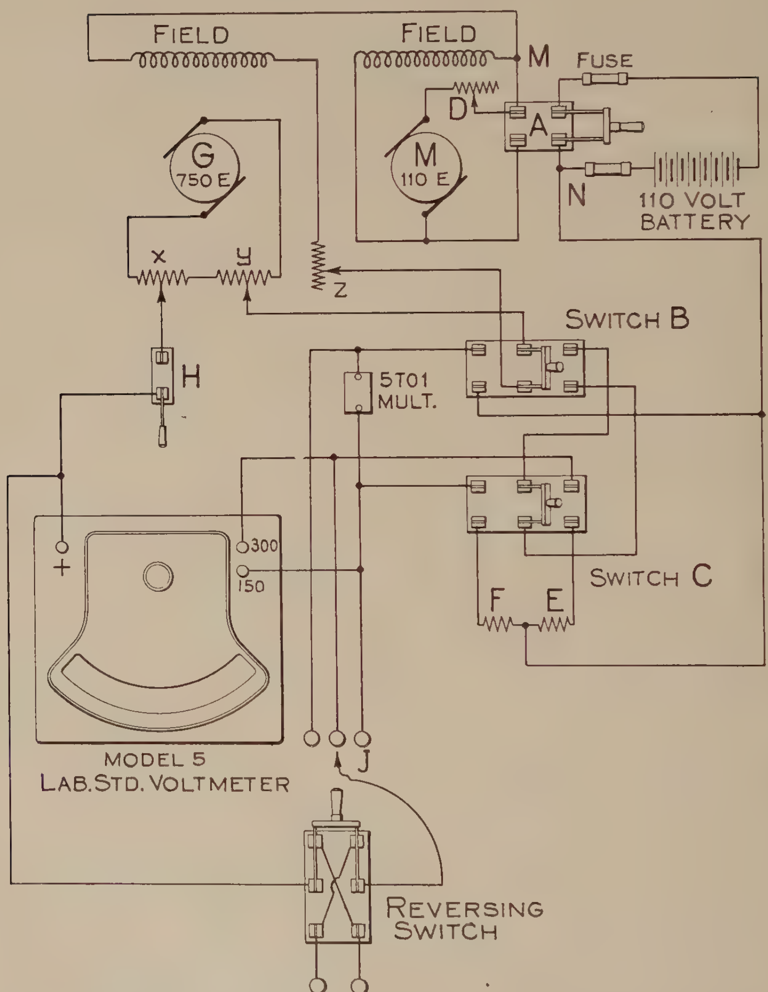
1 Model 5, Weston Standard Voltmeter, reading 0-3-15-150-300.
1 Model 5, Weston 5 to 1 Multiplier.
2 Voltmeter Switches, 5 points (A & B).
1 60 Ampere S. P. S. T. Knife Switch, or its equivalent.

7 Binding Posts.

1 60 Ampere D. P. D. T. Knife Switch.

1 750-Volt Storage Battery, 8 ampere hours, and proper facilities for charging.

(See page 33 for continuation of this list)



BINDING POSTS FOR INSTRUMENT BEING CHECKED

Fig. 21. D. C. Voltmeter Checking

Or 1 750-Volt Motor-generator Set.
Necessary fuse protection, ½ ampere, 600 volts.
16-inch Slide Wire Rheostats, as follows:
A—0.6 ohms.
B—50 ohms.
20-inch Rheostats:
R. 750—6,400 ohms.
R. 320—3,500 ohms.
R. 150—1,250 ohms.
R. 20—50 ohms.
R. 4—4 ohms.

Alternating Current Voltmeters

All alternating current voltmeters, except those of the induction type, may be checked on direct current, if the mean of two reversed readings is taken, using the facilities described under "Direct Current Voltmeters." Instruments of the movable iron type when checked in this manner with D. C. may be relied upon to within 1%. However, in most laboratories the number of alternating current voltmeters outnumbers the direct current type and only two, or at the most three, ranges are used. A simple and nearly foolproof method of checking alternating current voltmeters is shown in Figure 22. This method requires a Weston Model 326, Laboratory Standard Voltmeter having the desired ranges and a small transformer. This transformer has its primary divided into two windings, 110 volts each, with a secondary winding of 300 volts. Such a transformer is simple to construct and may be of only a few watts rating. By means of a series-parallel switch, either 150 or 300 volts may be obtained at the secondary terminals. A third pole is used on the switch, as shown, to select the proper range on the standard voltmeter. This makes it impossible to increase the voltage beyond the range of the standard voltmeter. The voltage is controlled by rheostats "A" and "B," which should have resistances of 50 and 3,200 ohms. The same results may be accomplished by the use of a standard potential transformer, 110 to 220 volts, used as an auto transformer. Such an arrangement will give either 220 or 330 volts for checking purposes. Regardless of the method used, the source of supply must be constant.

By means of different rheostats a standard 110-220 to 440-550 volt transformer may be used, placing stops on the rheostats to prevent the sliding con tact from increasing the voltage beyond the range of the voltmeter. The

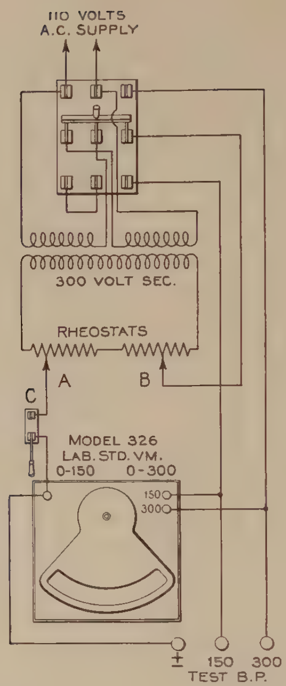


Fig. 22. A. C. Voltmeter Table

series-parallel switch may be used as a main switch if desired, but a smaller switch "C" is recommended.

Order List of Material (Fig. 22)

1 Weston Standard Voltmeter, Model 326—0-75—0-150—0-300 volts.
1 Transformer, 110-220 to 300 volts.
1 Knife Switch, 30 amperes 3 P. D. T.
1 Knife Switch, 60 amperes S. P. S. T.
1 Rheostat "A"—50 ohms.
1 Rheostat "B"—3,200 ohms.
3 Binding Posts.
Proper fuse protection.

Direct Current Ammeters

In checking ammeters, the problem of current is opposite to that required by the voltmeter. In the latter case a high voltage and a very low current is required, while with the ammeter, a high current at a very low voltage is

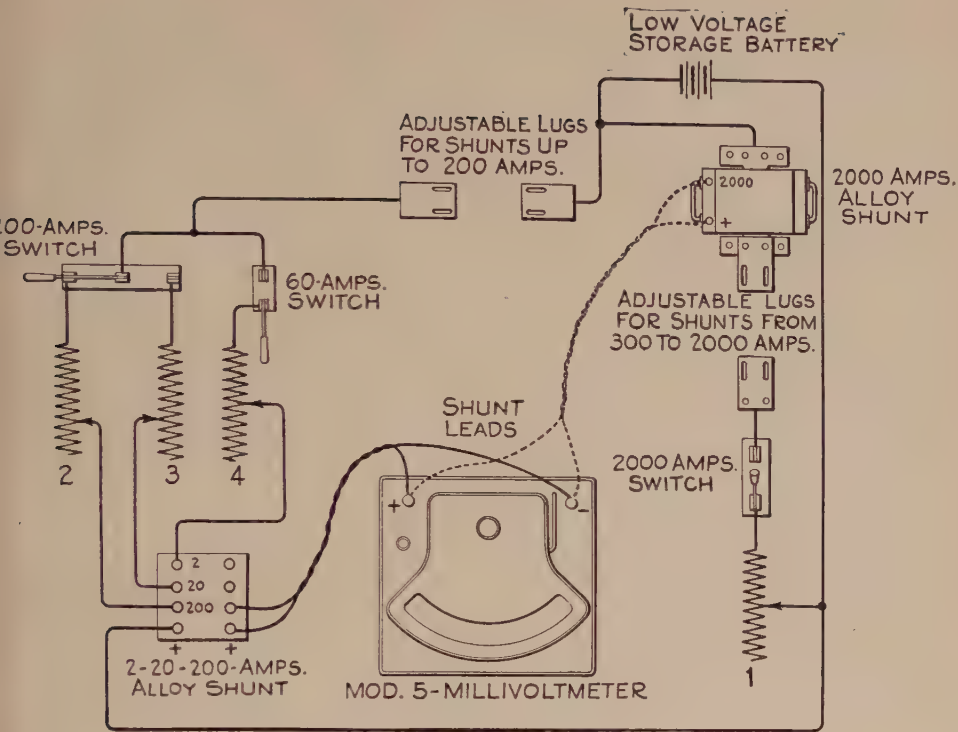


Fig. 23. D. C. Ammeter Checking

required. Both instruments in common require a steady source of supply to allow a comparison of the instruments and a regulating system for obtaining any desired value.

The best source of current is obtained from a four volt or six volt storage battery of sufficient capacity, depending upon the size of the instruments to be checked. If a low voltage, high current generator is used for charging, it may also be used in multiple with the battery when checking large ammeters. The desired instrument for standardizing ammeters is a Weston Model 5 Millivoltmeter, together with its shunts, connected as shown in Figure 23. In this Figure, facilities are shown for calibrating ammeters up to 2,000 amperes. Adjustable lugs are used in connection with the shunts so that any standard shunt may be placed in circuit without the use of tools. This is done by using copper blocks properly bored or slotted and having wing nuts for bolting the shunts in place. For controlling the heavy currents through the 2,000 ampere switch, shown in the diagram, some non-magnetic high resistance material

should be used such as carbon, manganin or special resistance material in strips or rod form as shown at I in Figure 23. Carbon rods having sufficient capacity to carry the full current are best adapted, or the use of brass pipe cooled by running water may be substituted. To obtain 2,000 amperes at 6 volts, the resistance of the circuit, including the shunts, etc., should not exceed .003 of an ohm. While a 2,000 ampere switch is shown in the diagram, undoubtedly one built for one-half that capacity could be used where the current is on for a short time, as these large switches will stand heavy overloads.

Rheostats 2, 3 and 4 should have sufficient resistance to allow only enough current to pass through the instrument for full scale deflection. If a slide wire rheostat is used, a stop can be provided for the runner so that it will not go beyond a certain point. If this is not desirable, a fixed resistance may be used in series with the regular rheostat for regulating the current.

Rheostat No. 2 in the Figure should preferably be of the carbon type and it might be well to use two or three in multiple, in order to obtain sufficient current for checking purposes. For 200 amperes the resistance of this circuit should not exceed .03 of an ohm. For the 20 ampere and 2 ampere circuits their limiting resistances are .3 and 3 ohms, respectively. A 60 ampere switch is recommended on the 2 ampere range, due to its mechanical strength. In designing this outfit be sure that wires carrying heavy currents are kept away from the instruments. This particular table or bench should be placed next to the one arranged for checking D. C. voltmeters. Such an arrangement will make it convenient for checking wattmeters and direct current rotating standard watthour meters, with the addition of some accurate timing device.

The 200 ampere and 60 ampere switches should never be on at the same time.

The shunts shown in the cut are the minimum number which could well be used. When better overlapping of ranges is desired, shunts in the ratio 1, 2, 5, 10, etc., amperes are recommended.

Order List of Material (Fig. 23)

1 Model 5, Weston Millivoltmeter with scales reading 0-2-20-200-2000 amperes with leads.
1 Weston Precision Shunt 2-20 and 200 amperes.
1 Weston Precision Shunt 2000 amperes.
3 Storage Cells, 200 ampere-hour capacity or larger.
1 2,000 ampere S. P. S. T. Knife Switch.
1 200 ampere D. T. S. P. Knife Switch.
1 60 ampere S. P. S. T. Knife Switch.

1 Adjustable rheostat (1) for 2,000 ampere range.
Adjustable rheostat (2) for 200 ampere range.
Adjustable rheostat (3) for 20 ampere range.
Adjustable rheostat (4) for 2 ampere range.
2 Sets adjustable lugs or terminals for holding shunts.
Facilities for charging batteries.

Millivoltmeters

Millivoltmeters in ranges up to 100 millivolts may be checked by using the Model 5 millivoltmeter already shown in Figure 23, describing facilities for checking direct current ammeters. A simple method is shown in Figure 24 and consists of a fixed resistor A and variable resistors B and C. The object of the fixed resistor is to make it impossible to increase the voltage in the instrument circuit dangerously beyond its maximum range. The adjustable resistors are for obtaining the various values of current. The value of these resistors will depend upon the source of current, whether it is from a dry cell or a single cell of a storage battery. The storage cell will give the best results, and under these circumstances the fixed resistor should have a resistance of 15 ohms and variable resistors having values given below. It is suggested that this equipment be made a part of the direct current ammeter checking facilities, making the standard millivoltmeter and one of the storage cells common to both tests.

Order List of Material (Fig. 24)

1 Fixed resistor (a), 15 ohms.
1 Adjustable resistor (b), 0.25 ohm.
1 Adjustable resistor (c), 3 ohms.
1 Single pole, single throw switch.
2 Binding posts.
Source of current supply.

Alternating Current Ammeters and Wattmeters

The most used and important facilities in the Central Station laboratory are those provided for checking alternating current ammeters, wattmeters and rotating standards. Such facilities should be so arranged as to be as foolproof and accurate as possible. There are several methods of accomplishing these results, but the scheme suggested in Figure 25 is strongly recommended on account of its extreme flexibility and range. It covers the checking of alternating current ammeters, either with or without their respective current transformers, in sizes up to 2,400 amperes. Wattmeters may likewise be checked as well as alternating current rotating standards.

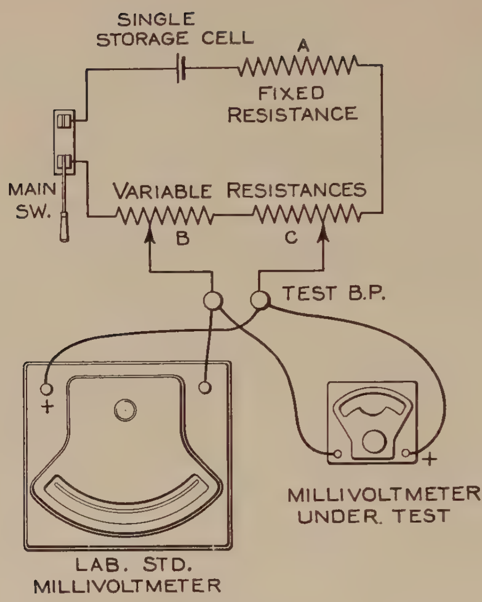


Fig. 24. Method of Checking Millivoltmeters

The scheme, as shown in Figure 25, has a range in current up to 2,400 amperes and in voltage up to 300 volts, but other voltages may be obtained as desired.

The outfit consists of a Weston Model 326 Laboratory Standard Wattmeter and a Standard Ammeter of the same model number. Both instruments have a double current range of 0-2.5 and 0-5 amperes. The wattmeter has three potential ranges, 0-75, 0-150, and 0-300 volts. For higher voltages multipliers or potential transformers must be used. By referring to Figure 25, it will be seen that the method consists of using a polyphase source of supply, three phase being used for illustration. A two phase current may be substituted if desired and will only change the style of "phase shifter" used.

One phase goes through a step down transformer for the current supply and all three phases through the "phase shifter" for the potential circuits.

The diagram is self-explanatory, but perhaps a brief description will not be out of place. The current for standardizing an ammeter, current transformer or supplying the current coils of a wattmeter is regulated by an induction regulator, adjustable reactance, rheostat or by the field control of the generator. Whatever method of control is used, except generator field, the

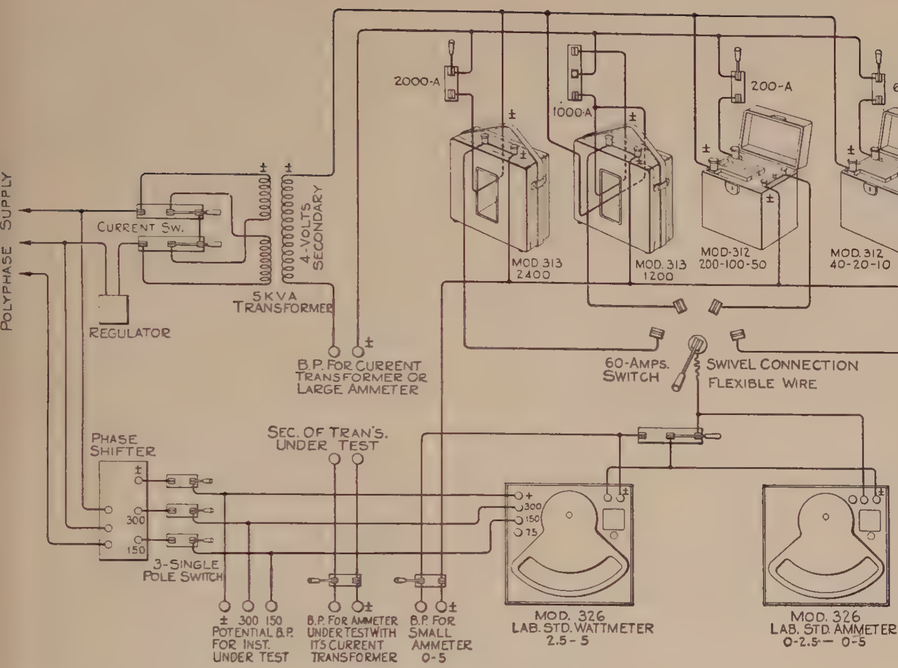


Fig. 25. Checking A. C. Ammeters, Wattmeters and Current Transformers

regulating device should be connected with the primary winding of the step-down transformer, as shown. A series-parallel main switch is used for giving a greater range in the transformer current. The current transformer used as a standard is connected into circuit by its individual switch, shown at the top of the diagram. Inserted primary or "through" types of transformers may be used in connection with double throw switches, so as to vary their ratio. This is better shown in the case of the 1,200 ampere transformer using a 1,000 ampere S. P. D. T. switch. When this switch is "up," two turns of the conductor form its primary winding and the ratio is then 600 to 5 or 120 to 1. If this switch is in its downward position only one turn is available and the ratio is 1,200 to 5, or 240 to 1.

The secondary of any of the standard transformers may be connected to the standard instruments and instruments under calibration by means of the swivel knife switch, as shown. Such a switch is mounted on the bench or table, using a large washer on both sides of the blade support so that it may be turned without loosening. A No. 10 B. & S. G. flexible wire is soldered to the stud and turns with the switch blade. Stops should be used to prevent

the blade from turning more than its required half circle. As all Weston Standard Current Transformers are supplied with short-circuiting switches, all are left "closed," except the one on the transformer in use.

The S. P. D. T. switch placed between the Standard Ammeter and Wattmeter is for cutting out either instrument if its use is not required. Various power factors may be obtained by means of the "phase shifter" shown at the left.

For the secondary connections of the current transformer, No. 12 B. & S. G. wire is recommended. A dry type of transformer is suggested for supplying the current and by placing it directly under the bench or table much copper may be saved. The size of such a transformer will depend upon the amount of current required for checking. As these transformers will stand heavy loads for short periods, a maximum rating of the largest instruments to be checked is unnecessary. Such a transformer will stand 100% overload for sufficient time to check several instruments.

If voltages above 300 are required for the potential circuits of wattmeters, it will be necessary to use a higher voltage "phase shifter" or arrange facilities for connecting into circuit potential transformers of the desired voltage. The Model 326 wattmeter will require a multiplier if the voltage is not over 750, or a potential transformer if the voltage is above 750. By purchasing the multiplier or potential transformers with the instrument these facilities may be used to check a complete polyphase metering outfit. When using these same facilities for checking rotating standards, some accurate timing device must be available. Furthermore, a steady source of supply is absolutely necessary for accurate work.

Order List of Material (Fig. 25)

1 Weston Model 326 Laboratory Standard Ammeter 0-2.5—0-5 amperes.
1 Weston Model 326 Laboratory Standard Wattmeter 0-2.5—0-5 amperes, 0-75-150-300 volts.
1 Multiplier for 750 volts or potential transformers depending upon voltage.
1 Weston Model 312 Current Transformer 40-20-10 amperes.
1 Weston Model 312 Current Transformer 200-100-50 amperes.
1 Weston Model 313 Current Transformer 1,200 amperes.
1 Weston Model 313 Current Transformer 2,400 amperes.
1 Transformer, single phase, 5 K. V. A. 110-220 volts primary to 4 volts secondary, dry type.
1 Current regulator or other control for primary of above transformer.
1 Phase shifter.
1 Special Swivel Knife Switch, 60 amperes, 4 points.

1 Main Knife Switch, 50 amperes, D. P. D. T.
1 Knife Switch, 60 amperes, S. P. D. T.
3 Knife Switches, 60 amperes, S. P. S. T.
9 Small binding posts.
2 Large binding posts.
Accurate timing facilities.
Proper bus-bars.
Proper fuse protection.

Watthour Meters

One of the important functions of the electrical or standard laboratory is the checking of watthour meters. Regardless of the size of the company, the checking of these meters is of prime importance and the laboratory of any public utility should have proper facilities for this work. With the large operating companies a separate department, called "The Meter Department," takes care of these meters, and the laboratory provides, or properly checks, their rotating standards by which customers' meters are checked. However, in most cases the electrical laboratory takes care of these meters.

The continual "turn over" of these meters makes it necessary to handle them rapidly, but accuracy must not be sacrificed in any case. Watthour meters should be checked before being placed in service, while in service, and when returned to the laboratory. The first and last tests are made in the laboratory where permanent facilities are available. When meters are tested in service, portable equipment is used, which has already been checked in the laboratory.

The subject of Watthour Meter Testing has been so well covered in the "Handbook for Electrical Metermen," published by the National Electric Light Association, that only a few suggestions will be made here.

Special benches should be provided for this work, properly designed to reduce to a minimum the labor necessary for checking and testing. The necessary facilities for this work may be "home made" or purchased from manufacturers who make a specialty of this material.

For a small laboratory where only a few meters are tested from time to time a simple and inexpensive switchboard, as shown in Figure 26, will be found convenient. All that is required are a few switches and some everyday attachment receptacles. Referring to the diagram, Figure 26, the current passes through the fused main switch shown at the left. Plug No. 2 is for use with an ammeter for determining the amount of current passing through the meters and for adjusting the load. The switch "A" short-circuits this plug when the ammeter is not in use. The "line" side of the

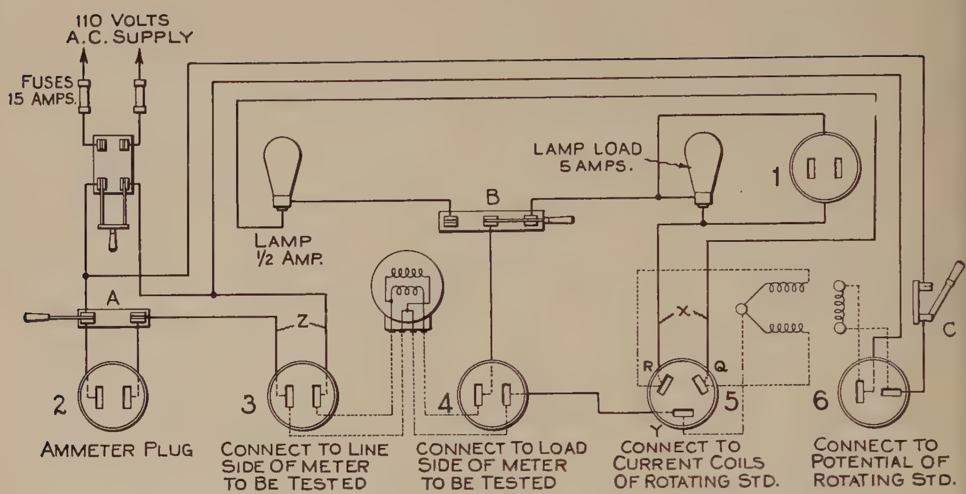


Fig. 26. Small Attachment Plug Board for Checking Watthour Meters

watthour meter under test is connected to plug No. 3 and the "load" side to plug No. 4. The current terminals of the rotating standard are connected through a three wire cap to plug No. 5. The light load line shown at "Q" connects to the 1 ampere terminal and the full load line shown at "R" to the 5 or 10 ampere terminal of the rotating standard. If the rotating standard used has only two current terminals using a switch for changing its rating, then plug No. 5 may be of the common two-wire type as used for the other connections. In this latter case connect lines "Q and R" together, as shown by line "X" and connect to plug direct. By means of switch "B," either light or full load may be placed upon the meters. Switch "B" to the left is for light load and to the right for full load. Incandescent lamps may be used for the load, the number used depending upon their size and type. The plug No. 1 is for using a toaster, heater or other load, if more current is required or for use with a 10 ampere meter. This plug (No. 1) will also be found convenient when the current or watthour consumption of some appliance or small motor is desired. In this case the other, or permanent, load is disconnected. The rotating standard has its current terminals connected to plug No. 5 and its potential or voltage terminals to plug No. 6. It is necessary to use the polarity type of attachment receptacle, Nos. 5 and 6, with the rotating standard in order that the proper relations may exist between current and voltage. The other receptacles may be of the ordinary type if desired. Switch "C" controls the potential circuit of the rotating standard through receptacle No. 6.

The above connection is for use with the ordinary house-type meter, having both sides of the circuit passing through the meter. It is very important that the connections be properly made as shown so that the current taken by the potential coil of the meter under test does not pass through the Rotary Standard. For this reason do not connect the rotating standard to the "line" side of the meter under test. This same system may be used for 220 volt meters by changing the supply circuit voltage and using a proper 220 volt load. A small portable stand, as shown in Figure 27, will be found convenient for keeping the meter in place while testing or the meter may be mounted on the test board itself if desired.

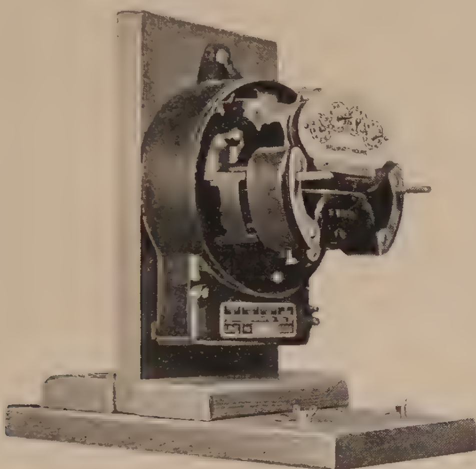


Fig. 27. Stand for Watthour Meter

In some cases where only a very few watthour meters are in use the expense of a rotating standard is not warranted. To offset its use a regular service type watthour meter may be substituted by connecting its potential circuit like that of the rotating standard shown in Figure 26. By removing the dial and marking the rotating meter disc in hundredths, its use as a standard will be greatly simplified. If it is not practical to mark the disc itself, one made on thin paper may be pasted on the disc and will answer equally well. Such a meter should be checked from time to time to insure its accuracy.

List of Material Required (Fig. 26)

1 Main Switch D. P. S. T. fused, 30 or 60 amperes.
1 Switch S. P. D. T. (B).
2 Switches S. P. S. T. (A and C).
4 Attachment receptacles (1-2-3-4).

1 Attachment receptacle, polarity type (6).
1 Attachment receptacle, polarity type, 3 pole (5).
Lamps and sockets for load.
Necessary plugs or caps with fixed terminals for connecting to meters.
1 Rotating Standard.

Power Factor Meters

Single phase power factor meters may be checked approximately with the facilities already shown in Figure 25, with the addition of an accurate alternating current voltmeter. A sine wave source of supply will be necessary for accurate work.

Polyphase power factor meters are somewhat more difficult to check than most indicating instruments, and we recommend that they be sent to the Weston laboratory or the U. S. Bureau of Standards when in need of checking.

Frequency Meters

In order to check a frequency meter, the R. P. M. and number of poles of the generator must be accurately known. If all points on the scale of the instrument are to be checked, an adjustable speed alternating current generator will be required. An accurate stop watch and revolution counter are necessary and the work may be done at any of the alternating current tables or benches, that of the alternating current voltmeters being, perhaps, preferred.

If an adjustable speed generator is used, it is very desirable to use in connection with it an accurate speed indicator, calibrated in frequency or R.P.M. This can be checked at any desired frequency by means of the stop watch and revolution counter and then other parts of the scale of the frequency meter under test can then be checked from the speed indicator directly. Probably the most accurate speed indicator for this purpose is the Weston Model 44, shown in Figure 64. This is a high grade D. C. magneto, which generates six volts per 1,000 R.P.M., electrically connected to a high resistance D. C. Voltmeter, which may be calibrated in cycles or R.P.M. as desired. The instrument may be used at any reasonable distance up to 500 feet or more from the generator.

Current Transformers

The checking of current transformers in connection with their respective instruments may be carried out with the facilities already shown in Figure 25. Ratio tests of current transformers may be made by comparison with standard transformers by using two standard ammeters. The ratio test will require a second standard or an accurate reading ammeter connected to the secondary of the transformer under test.

If, however, it becomes necessary to obtain the phase angle of these transformers, other facilities must be available, such as the "Sillsbee" Testing Outfit.

Potential Transformers

Undoubtedly the best practical method of checking potential transformers is the one originated by the Weston Electrical Instrument Company, using a Weston Model 333 Comparator Voltmeter. This instrument is designed for quickly and precisely comparing the ratios and phase angles of two potential transformers, which have approximately the same ratio. In the practical use of the instrument, one of the transformers is used as a standard; the ratio and phase angle having been once for all exactly determined by direct measurement by the potentiometer, or other methods in the Weston or other standardizing laboratory. In connection with the standard transformers, this instrument then offers a means for quickly determining the exact ratio and phase angle of any particular transformer of the same nominal ratio.

The instrument is a very sensitive electrodynamometer voltmeter, the field coils of which are separately excited from a source of constant voltage. The voltmeter scale, therefore, is not congested as it approaches zero, as is the case in A. C. voltmeters having self-excited field coils, but is uniform like that of a Weston permanent magnet direct current instrument.

The field and movable coil circuits are compensated for their self-inductance so that the currents in them are in phase with the applied voltages.

The instrument has three ranges: 250-0-250, 25-0-25, 2.5-0-2.5 volts, with the zero in the center of the scale.

It can be made in other ranges, however, to suit particular requirements. The field coil circuit is provided with a plug switch so arranged that the circuit may be supplied from any voltage from 95 to 125 volts in steps of 5 volts.

The current required for the measuring circuit is less than 6 milliamperes for the full voltage on any range. This current is so small that the error introduced by it may be neglected; it being less than 1/25 of 1% on a 50 watt transformer of average design, even if its ratio differs from that of the standard by as much as 2%. As this difference becomes less, as it generally will in practice, the error will diminish very rapidly to zero.

The lowest range scale, 2½ volts, is divided into 0.05 volt divisions. In testing a transformer having a 110 volt secondary, each division therefore represents less than 1/20th of 1% difference in ratio, and this may be extended by estimation to 1/100 of 1%.

The transformers to be compared have their primaries connected to the same source of voltage, and their secondaries connected in series opposition across the movable coil circuit of the voltmeter, as is shown in Figure 28. The instrument itself is shown in Figure 29.

In Figure 28 is shown a convenient method of mounting the facilities on a table or bench. As shown, a three-phase source of supply is used, but a two-phase system may be used as indicated at the right of the diagram. In the

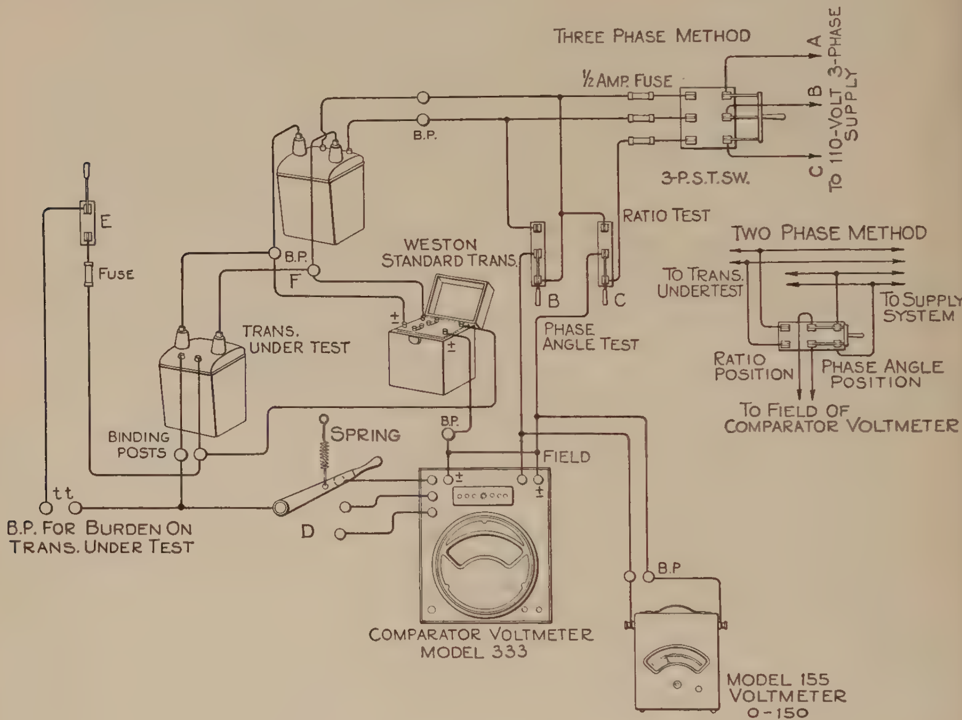


Fig. 28. Checking Potential Transformers

latter case the main switch "A" has four poles, and a D. P. D. T. switch is substituted for the two S. P. D. T. switches "B and C."

In using this method, two potential transformers have their secondaries in opposition. However, if a mistake should be made in the polarity, double voltage would be impressed upon the instrument. Although the instrument is supplied with a scale reading from 0 to 250 volts, the operator may forget to use this scale when first checking the polarity. For this reason we suggest some form of a spring switch, as shown at "D" in the diagram Figure 28.

Fig. 29. Model 333 Comparator Voltmeter

The switch arm is held on to the 250 volt connection by means of a spring. After the correct polarity exists between the transformers, the switch arm is moved to the next contact connecting it with the 0-25 volt coil. If the primary of either transformer should be "open," a deflection of more than 2½ volts would be obtained and would thus be noticed. If the transformers and their polarities are correct, the switch "D" is placed on the third or nearest contact (2.5 volts) and held there until the readings have been taken. When released, the switch arm returns automatically to its 250 volt position.

Switch "E" is used for controlling the "burden" on the transformer being checked.

In the diagram, a voltmeter is shown connected to the field circuit of the instrument. This may be omitted if the supply voltage is known. The main switch is connected to the three phase lines, A, B, C, and the independent switches B and C are for use in obtaining ratio and phase angles as described in Chapter XI.

The binding posts shown at "F" are for use only when the voltage is not over 2,200 and should be carefully insulated with hard rubber or fibre. A medium size binding post is recommended at "F," as three wires connect to each. For primary voltages above 2,200 it is best to make connections directly between the transformers and not use binding posts.

List of Instruments and Accessories Required (Fig. 28)

1 Model 333 Weston Comparator Voltmeter.
1 or more Weston Standard Potential Transformers, Models 311 or 250.
1 or more Step up transformers for supplying high potentials to test and standard transformers, Models 311 or 250.
1 Weston Voltmeter Model 155, reading 0-150.
*1 Main knife switch, 60 amperes, 3 P. S. T.
*2 Knife switches "B and C," 60 amperes, S. P. D. T.
1 Knife switch, "E," 60 amperes, S. P. S. T.
1 Special Spring Switch, "D," 3 point.
9 Small binding posts for 2,200 volt transformers.
2 Specially insulated binding posts for 2,200 volt transformers.

(If a higher voltage than 2,200 is used, omit the above two binding posts shown in the high voltage circuit and connect transformer directly.)

Necessary fuse protection.

Ampere-Hour Meters

No special facilities are necessary for the checking of ampere-hour meters, as this may be done on the table provided for checking direct current ammeters, as already shown in Figure 23, with the addition of some accurate timing device.

Rotating Standards

Facilities for checking the well-known rotating standard should be very carefully and simply laid out, as this is one of the most important tests the laboratory is called upon to make. Any laboratory should have the proper facilities available at all times for checking these standards. A small company serving only a few hundred customers should make arrangements with some standardizing laboratory for checking its rotating standards periodically.

A rotating standard is in reality a specially constructed watthour meter and may therefore be checked on the same apparatus as is used for checking a wattmeter, provided some accurate timing device is available. Some form of "Master" clock is preferable to the ordinary stop-watch, on account of its greater accuracy. However, an accurate stop-watch properly used will make a fair substitute.

Direct current rotating standards may be accurately checked on the table or bench, as already suggested for direct current voltmeters and ammeters

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* If supply circuit is two-phase, a 4 pole S. T. and a D. P. D. T. knife switch should be substituted.

(see Figs. 17 and 23). Alternating current rotating standards, as already suggested, may be accurately checked, as shown in Figure 25. They require the same facilities as the indicating wattmeter with the addition of an accurate timing device, being automatic if possible. A steady source of current is absolutely essential for accurate work, using the same wave form as found upon the main system. If a "Master" rotating standard is available, the working standard may be compared with it. In this case only the "Master" standard is checked with the indicating instruments.

Resistance

Many of the larger laboratories find it advisable to have facilities permanently available for measuring various values of resistance. The most accurate method within certain limits is by means of the well-known Wheatstone

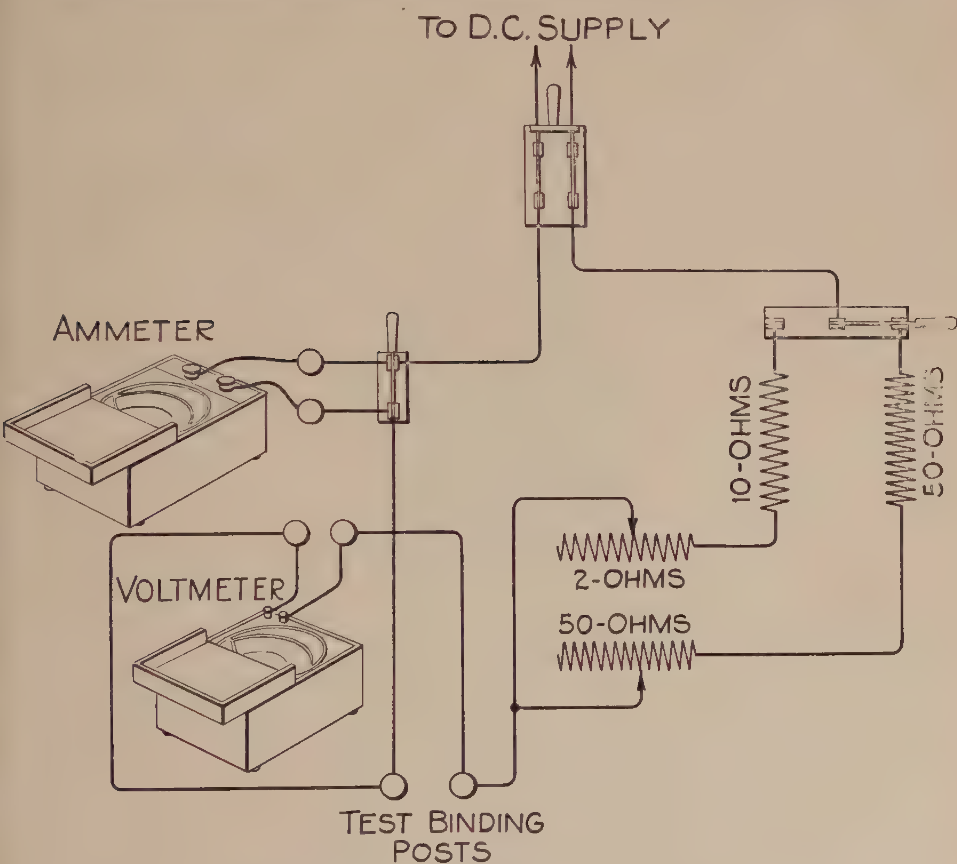


Fig. 30. Connections for Resistance Measurements

bridge. However, for general laboratory purposes the "Drop-of-Potential" method will answer in practically all cases where current may be passed through the circuit to be measured. Connections for this test are shown in Figure 30.

The circuit where the resistance is to be measured is connected to the "test binding posts." The S. P. S. T. switch above these binding posts is used for cutting out the ammeter. At the right is shown a S. P. D. T. switch for connecting two fixed resistances in series with the variable resistance and the '"test binding posts." This is to limit the current and make short-circuits impossible. In this figure the supply circuit is assumed to be 110 volts.

In many cases this work can be performed, if great accuracy is desired, on the Standard D. C. Ammeter and Voltmeter table already shown in Figures 17 and 23.

For work in the field where portable instruments are required, a Weston Model 1, Direct Reading Ohmmeter will be found extremely useful. This instrument is shown in Figure 31 and is made in several ranges from a few ohms to 3,000. With two instruments, each having a triple range, resistance up to 3,000 ohms may be accurately measured. No other equipment is necessary except a few dry cells.

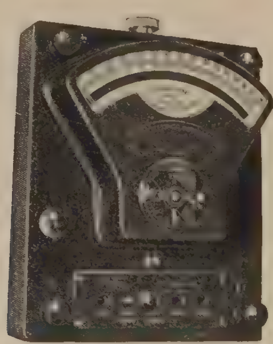


Fig. 31. Model 1 Ohmmeter

Material Required (Fig. 30)

1 D. P. S. T. Main Switch, 60 amperes.
1 S. P. S. T. Ammeter C-O Switch, 60 amperes.
1 S. P. D. T. Resistance Switch, 60 amperes.
6 Binding posts.
1 Fixed Resistance, 50 ohms, 2 amperes.
1 Fixed Resistance, 10 ohms, 10 amperes.

1 Adjustable Resistance, 50 ohms, 2 amperes.
1 Adjustable Resistance, 2 ohms, 10 amperes.
1 Weston Voltmeter Model 45, Reading 0-150 and 0-15 and 0-3 volts.
1 Weston Ammeter Model 45, Reading 0-15 and 0-5 amperes.
Proper fuse protection.

Chapter IV

HIGH VOLTAGE LABORATORY

With the larger operating companies it is often necessary to have facilities available for making high voltage tests on insulators, cables, oils and miscellaneous insulating material. These tests can be divided into two groups, the first where a permanent testing outfit is installed in the laboratory, and the second covering portable equipment mounted on trucks. These latter facilities are so special and the problems so varied that no special suggestions are being made. On the other hand, suggestions on permanent installations may be of interest to some of the larger operating companies who are planning to add high voltage testing to their present activities.

As a rule, the greatest problem is to find sufficient room for housing the high voltage laboratory. This work is difficult where space is limited and requires careful consideration from the designer of the laboratory. In Figure 32 is shown the arrangement of the equipment in a laboratory for making tests with voltages up to 200,000. To cover these various voltages five transformers are provided. The first one has a maximum rating of 2,200 volts, the second 6,600 volts, and the third a range of 16,500 to 33,000. Both terminals on these transformers are insulated from ground, but for high voltages, on account of expense and the space occupied, transformers having the middle point of their high tension winding grounded are recommended. The fourth transformer, shown in Figure 32, is arranged for voltages up to 50,000, while the fifth transformer, which is rated at 100 kilowatts, shown in the background of the picture, has its secondary wound for 200,000 volts. The transformers mentioned above are rated at five, ten, fifty, fifty and one hundred K. V. A., respectively. In this laboratory all low tension wiring is placed underground and the high tension conductors are located overhead.

Transformers should have sufficient capacity so that the current required at high potentials will not tend to lower the voltage of the transformer or alter the wave shape of the supply circuit. Furthermore, it is not a very

Fig. 32. High Voltage Laboratory

expensive matter to increase the kilowatt capacity of a high voltage transformer, as a certain minimum size is necessary for insulation and therefore an ample size of conductor may just as well be used.

The room adjoining the laboratory, shown in Figure 32, was designed for housing a 1,000,000 volt 1,000 K. V. A. testing outfit. This outfit was not installed, as the late World War made it impossible to complete the entire

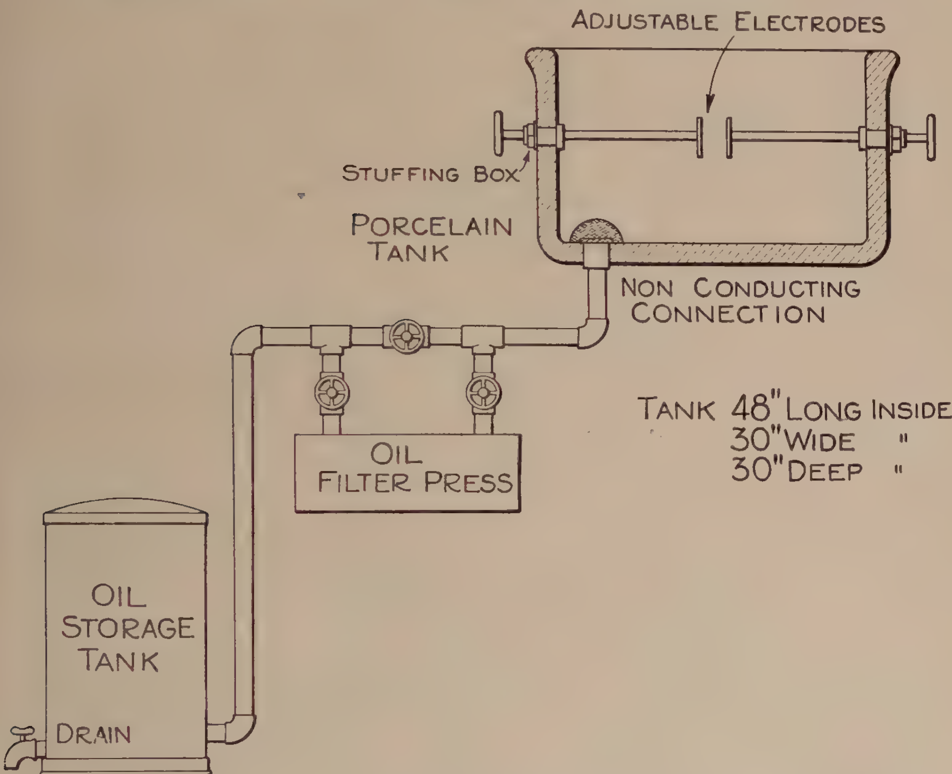


Fig. 33. Oil Tank for High Voltage Testing

laboratory. The equipment was finished some years later and is now in use at Pittsfield, Mass.

It is advisable to locate the high voltage laboratory away from other activities and preferably in a separate building, or at least in a room by itself. The room *must be quiet* and unnecessary noise avoided, especially that of rotating machinery.

The subject of auxiliary fittings should be considered, especially proper tables for carrying out the tests, all of which are quite varied. Water tanks

Fig. 34. Oil Tank in High Voltage Laboratory

are often required for testing cable, and oil tanks are necessary where breakdown tests of insulating material are required.

If many breakdown tests are to be made under oil, it is best to have the tank so piped as to make the problem of filling and emptying simple. Such a tank and system is shown in Figure 33 and has been found very satisfactory for all voltages up to 300,000. This tank is also shown in Figure 34, which was made from a photograph taken before the installation was complete. The oil, however, was forced into the tank by compressed air and allowed to drain back into the storage tank by gravity. Through each filling process the oil was filtered. Some form of a pump will be found better than compressed air for filling the test tank. Compressed air carries moisture and makes some form of a drying system necessary.

In the foreground of this same picture is shown one of the observation desks containing the safety switch, which is also shown in Figure 32 and in the diagram Figure 35. From this same desk the lights in the room could also be controlled.

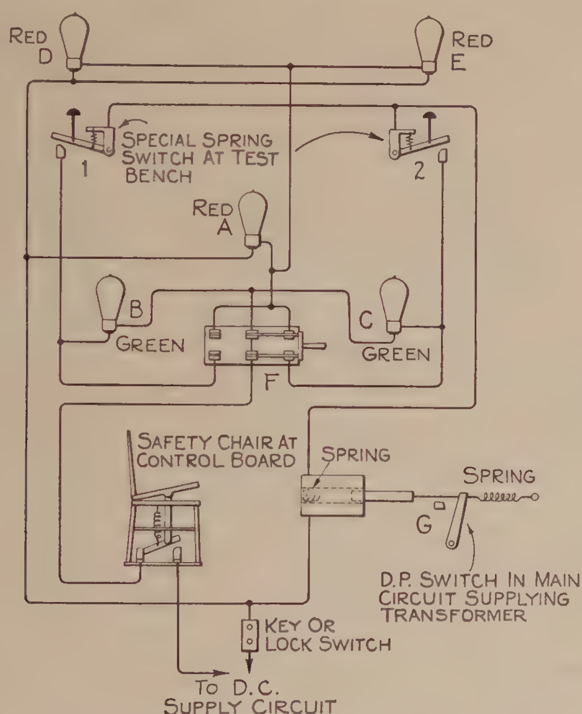


Fig 35. Protective System for High Voltage Laboratory

Fig. 36. Safety Chair

Just back of the observation desk is shown a metal covered table with brass discs of various sizes for testing insulating cloth. This table was supplied from the high tension system with voltages from 2,200 to 50,000.

Different sizes of brass discs are available for testing various cloths and other flat insulating material requiring a di-electric test. All of these discs have rounded edges, as any sharp corners must be avoided. The observation desks or control tables contain shelves for keeping the necessary supplies, working forms, etc., for operating the laboratory.

One of the most essential features in a high voltage laboratory is adequate protection for its operators. This is a point that should not be overlooked, especially when more than one man is employed for the work. In Figure 36 is shown a chair containing a false bottom which operates a switch. This chair is located in front of the switchboard, as shown in Figure 32. On each of the testing benches is located a spring safety switch which must be held in position before a test can be made. One of these stations may be seen in Figure 32. A diagram of connection of this system is shown in Figure 35. In operating the system, one man observes the test, getting as near the apparatus as safety permits, while the second operator sits in front of the switch-

board and handles the switches, regulates the voltage and records the results of the tests as far as voltage or current readings are concerned. The system operates as follows: When the test is about to be made, the operator takes his place at the switchboard. Just as soon as the observer has made the necessary connections and is ready for the test, he pushes down the spring switch (1 or 2), shown in Figure 35. This lights a green light "B" or "C" in front of the switchboard operator. This shows the switchboard operator that the observer is in his proper position. The switchboard operator then places his control switch, "F," in the position that covers the particular station where testing is to be done and this immediately lights a red light, "A," on the switchboard and at all control stations, "D" and "E," showing both parties that the high tension current is either "on" or about to be placed "on." The switchboard operator can then throw the current on to the particular transformer by the proper switch, as the circuit will be complete when the solenoid switch "G" operates. It is evident that if either party leaves his position the current will be turned "off" by means of the solenoid switch "G." Furthermore, a lock switch is also used in this system having its key in the hands of the superintendent or engineer in charge of the laboratory. This makes it necessary for the proper authority to be given before the equipment can be used. Such a system is desirable on all occasions and especially those where noise and other disturbing factors are present in the high voltage laboratory. In connection with this system a signal bell is used for voltage control. In some cases the chair shown in Figure 36 will give all the protection necessary, and will give adequate protection for high potential glove testing or similar tests, requiring the services of only one engineer. When used in this way, the double pole switch on the bottom of the chair is connected between the main switch and the testing transformer.

The voltage regulation of a high tension transformer is best taken care of by controlling the field of the generator supplying the current. But where this control cannot be obtained it is best to use the potentiometer method for

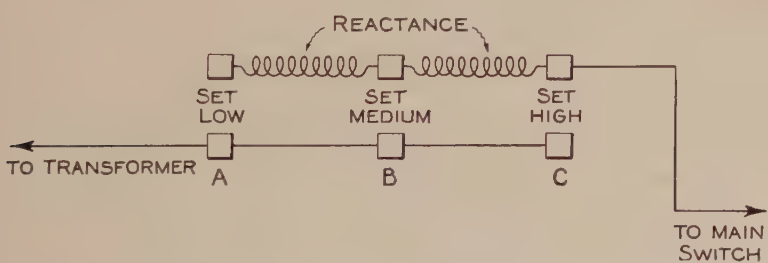


Fig. 37. Circuit Breaker Protection for High Voltage Transformers

transformers up to 50 K. V. A. and the series induction regulator for transformers of larger capacity, although these methods introduce irregularities in the wave form.

The use of a series-parallel switch in the low voltage circuit is desirable in all cases for giving a better ratio variation in the transformer.

For proper protection of transformers, especially in the larger sizes, the use of three circuit breakers, as shown in Figure 37, is suggested. This relieves the strain on the breakers and tends to reduce the high voltage surge in the transformer windings. It breaks the short-circuit current of the primary in three steps. Short-circuiting switches should be used with all ammeters in the primary circuit to avoid injury to the instrument when breakdown tests are made.

An independent generator, having a low armature reactance and distributed field winding is strongly recommended for supplying current for high potential testing transformers. This generator should be of sufficient capacity to maintain its voltage and wave form under load. For general testing a generator having a rating of 50 K. V. A. will be adequate for voltages up to 100,000, but for higher voltages the generator should be rated at considerably above this capacity.

The measurement of high potentials may be made by calibrated needle or sphere spark gaps, but the most satisfactory method is by means of the so-called "voltmeter coil," which is wound parallel to the high voltage winding of the transformer. The Model 341 Voltmeters are well adapted for use with the voltmeter coils on account of their high resistance and accuracy.

Facilities for conducting rain tests on high tension insulators should be located in a separate room and preferably out of doors where the climate permits.

Chapter V

ACCESSORY FITTINGS

All laboratories require an assortment of accessory fittings, depending upon the services performed and the amount of field work covered. In many cases the success or failure of the entire test has depended entirely upon the proper accessory fittings used, so before making any tests we strongly recommend making a preliminary study of the system to determine just how the work can best be conducted.

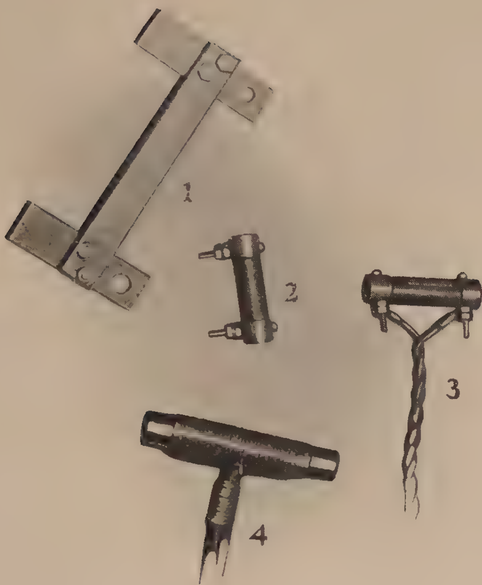


Fig. 38. Cutout Fuses Arranged for Instrument Connection

Many of the accessories that are used about the laboratory are necessary when making tests in the field.

One of the greatest obstacles encountered by the testing engineer is the necessity of connecting measuring instruments into the various circuits without stopping the machinery, thereby consuming a large amount of time and interrupting service. Illustrated herewith are several practical methods by which this difficulty may be overcome. They have proven successful for many years and on many occasions.

Fig. 39. "Dummy" Cartridge Fuse in Use

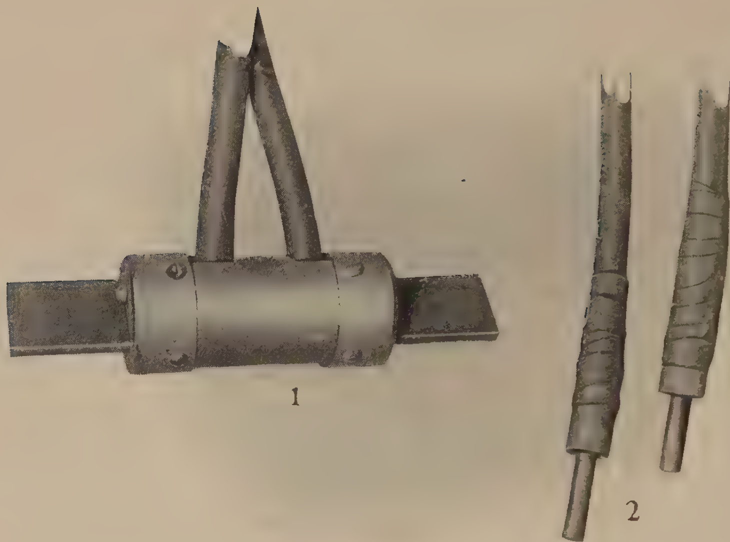


Fig. 40. Converted 200 Ampere Fuse

The most convenient method of connecting measuring instruments into the circuit is generally through the fuse cutouts and several types of fuse block connections are shown in this chapter.

By referring to Figure 38, the following suggestions will be readily understood. At "2 and 3" are shown a common 60 ampere 250 volt cartridge fuse with its interior entirely removed through the end caps. Holes have been drilled which will take an 8-32 screw. Three nuts are placed on each of these screws (one inside the fuse), which make terminals for the flexible cords.

Fig. 41. Single Stranded Conductor
of 300 Ampere Capacity

Fig. 42. 1500 Ampere Multiple Conductor

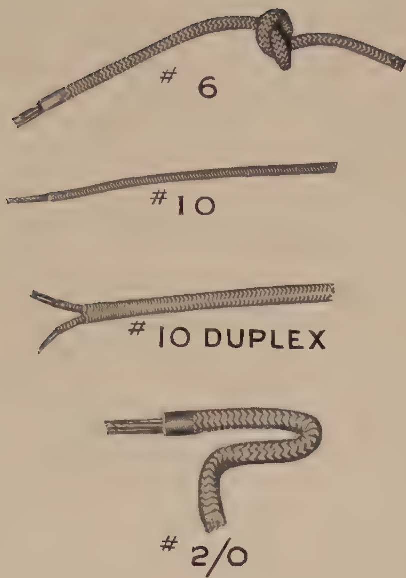


Fig. 43. Flexible Testing Cable

(Figure 39 shows the "dummy" fuse in use.) At "4" in Figure 38 is shown this same type of fuse made up for use in 600 volt cutouts. This latter connection has been insulated by means of common friction tape and is bound together with twine. At "I" is shown a "home-made" connector suitable for use in the 100 ampere standard cutout. It is made out of a common piece of copper bus-bar insulated by a piece of dry hard wood with holes drilled for bolting the lugs in place.

Figure 40 shows a 200 ampere fuse made up in this same manner with heavy flexible conductors. At "I" is shown the converted fuse with its terminals marked "2." These conductors do not come out parallel with the blades, but are offset so as to allow the easy handling of the connections. Figure 41 shows a single conductor jumper ready to bolt to apparatus and having a capacity of 300 amperes. Figure 42 shows a multiple conductor jumper having a capacity of over 1,500 amperes.

By pulling out the good fuse from the cutout with one hand, then with the other hand immediately inserting any of the temporary connections shown above, instruments can be placed in circuit so quickly that the motor or other apparatus will not be disturbed. This method is only a suggestion, and many others can be used which would prove equally efficient. When good fuses

Fig. 44. Insulated Test Clips

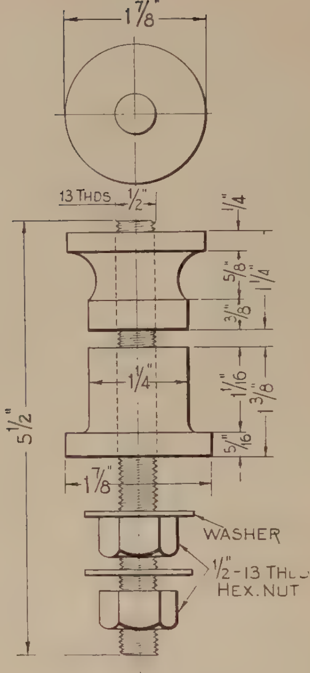


Fig. 45. Drawing of Large Binding Post

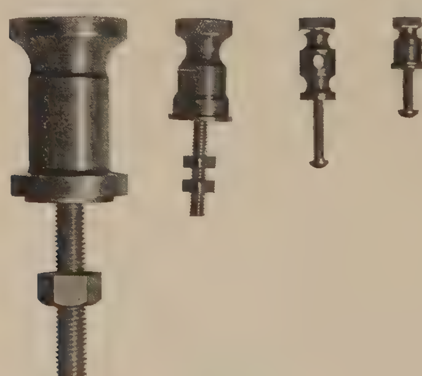


Fig. 46. Binding Posts

are removed be sure that the circuit is protected elsewhere. It is a good plan to have special fuses mounted on the test table or box.

Figure 43 represents cotton covered flexible cable which can be used for making the various connections between the instruments, transformers and

circuits under test. This wire does not have a heavy insulation and it is often necessary to reinforce it with common tape. By doing this, keeping it away from dampness and handling it properly, it will meet the bulk of the requirements. Where fairly long runs of 25 feet or over are necessary, duplex cable is recommended for connecting instruments and current transformers. A piece of 2/0 cable which has been bent so as to show its extreme flexibility is shown at the bottom of the Figure 43.

Figure 44 represents insulated test clips, which are very convenient in this class of work and can be obtained in various sizes.

It is very essential that these accessory fittings be made up properly and kept on hand for instant use whenever tests are desired. They are an important part of the testing equipment, and if you are unable to locate any of this material or wish further suggestions, our engineering department will be pleased to assist you upon application.

It is often difficult to obtain large binding posts for use with heavy currents. For this reason a working drawing of a large binding post is shown

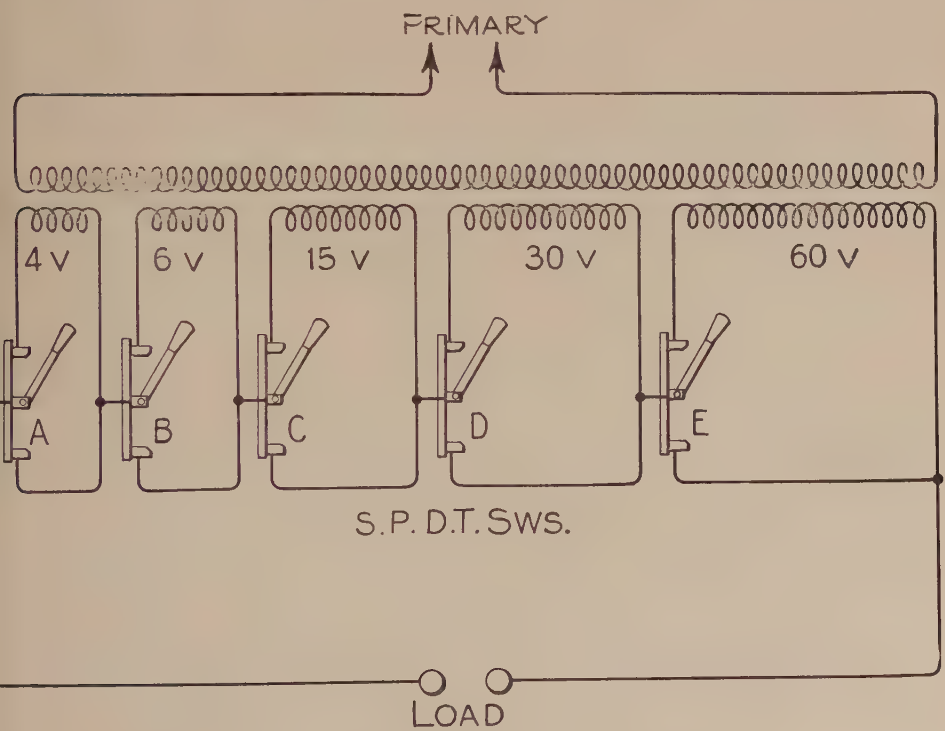


Fig. 47. Variable Voltage Testing Transformer

in Figure 45, which will carry 100 amperes continuously and a larger current for short periods of time. This binding post is also shown on the right in Figure 46 for comparison with standard sizes on the market. The small binding post on the right is the size furnished on relays, instruments, etc.

For cutting into D. C. circuits, a jumper containing a shunt may be clamped on to the terminals of a knife switch. For an A. C. circuit, a current transformer may be shunted around the switch.

By means of a small transformer, arranged as shown in Figure 47, a very flexible combination of voltages may be obtained. When winding the secondary, both ends of the various coils are brought out and not the usual system of taps that is found on most transformers. By sacrificing the efficiency of such a transformer, each coil may be built for a considerable proportion of the total capacity. With the arrangement as shown a large number of steps from 4 to 115 volts may be quickly obtained without the possibility of short-circuit in case a mistake is made in the use of the switches. The following table gives the position of the switches for obtaining any particular voltage. Other values than those shown may be obtained by designing the transformer for the requirements of the testing.

Variable Voltage Transformer Voltages

Load Voltage	*Position of Switches A B C D E*	*Load Voltage*	*Position of Switches A B C D E*
4	U-D-D-D-D	66	D-U-D-D-U
6	D-U-D-D-D	70	U-U-D-D-U
10	U-U-D-D-D	75	D-D-U-D-U
15	D-D-U-D-D	79	U-D-U-D-U
19	U-D-U-D-D	81	D-U-U-D-U
21	D-U-U-D-D	85	U-U-U-D-U
25	U-U-U-D-D	90	D-D-D-U-U
30	D-D-D-U-D	94	U-D-D-U-U
34	U-D-D-U-D	96	D-U-D-U-U
36	D-U-D-U-D	100	U-U-D-U-U
40	U-U-D-U-D	105	D-D-U-U-U
45	D-D-U-U-D	109	U-D-U-U-U
49	U-D-U-U-D	111	D-U-U-U-U
51	D-U-U-U-D	115	U-U-U-U-U
55	U-U-U-U-D		
60	D-D-D-D-U		
64	U-D-D-D-U		

U = Up.
D = Down.

Chapter VI

FACILITIES FOR FIELD WORK

As it is impossible to bring station and sub-station equipment to the laboratory, some means must be provided for performing the necessary tests and checking in the field. This means that a portion of the laboratory facilities should be made portable.

Work in the field should be highly systematized and carefully planned, especially if it is to become routine. Such work must not interfere with the operation of the station in any way and the life hazard should be reduced to a minimum.

Fig. 48. Portable Test Table in Use

Fig. 49. Box for Portable Test Table

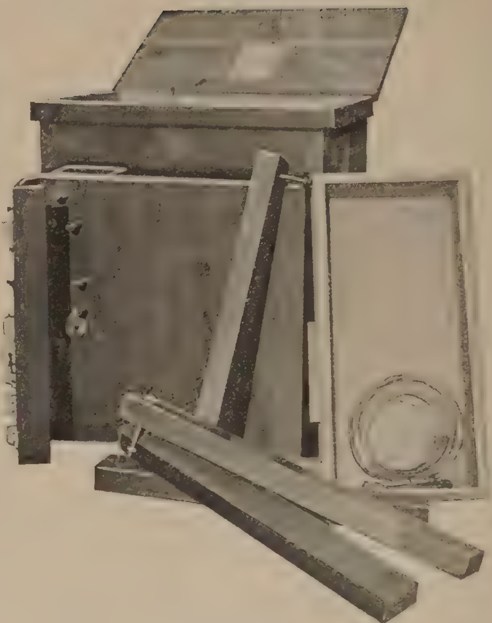


Fig. 50. Portable Test Table and Box

Fig. 51. How Test Table Fits in Its Box

The ease or difficulty with which field tests and checking may be made depends, first of all, directly upon the original design of the installation. If current and potential test clips have been provided in meter and instrument

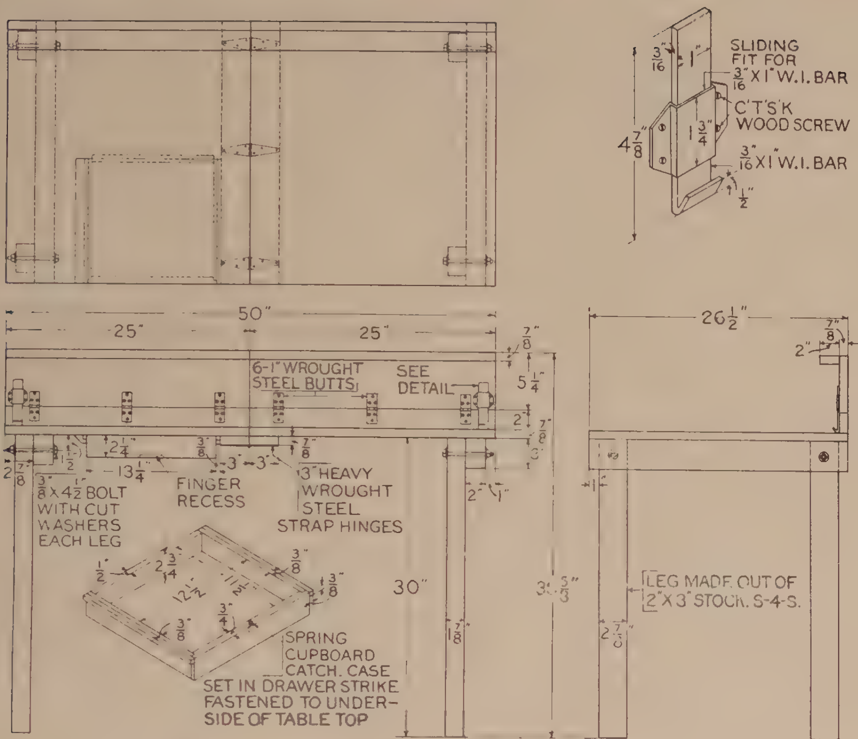


Fig. 52. Working Drawing of Portable Test Table

Designed by E. S. Lincoln, Consulting Engineer

circuits, the field work will be greatly simplified, especially if placed on the front of the switchboard panel. In some plants, especially the older ones, it is extremely difficult to connect into the instrument and meter circuits, without danger to both plant and operator. When making the first tests it would be well to make the necessary changes so that future work may be more easily accomplished.

Switchboard manufacturers should co-operate with the electrical laboratory and design installations in such a way that field work may be easily accomplished. Whatever extra expense is incurred will be saved many times over in the saving of the laboratory engineer's time and reduced life hazard. It should be possible to connect testing instruments into any circuit requiring tests without interrupting the service, and to examine oil switches and circuit breakers while "dead." This calls for proper design.

However, the best designed installation is not all that is necessary for first-class accurate work. The transportation of instruments and accessory equip-

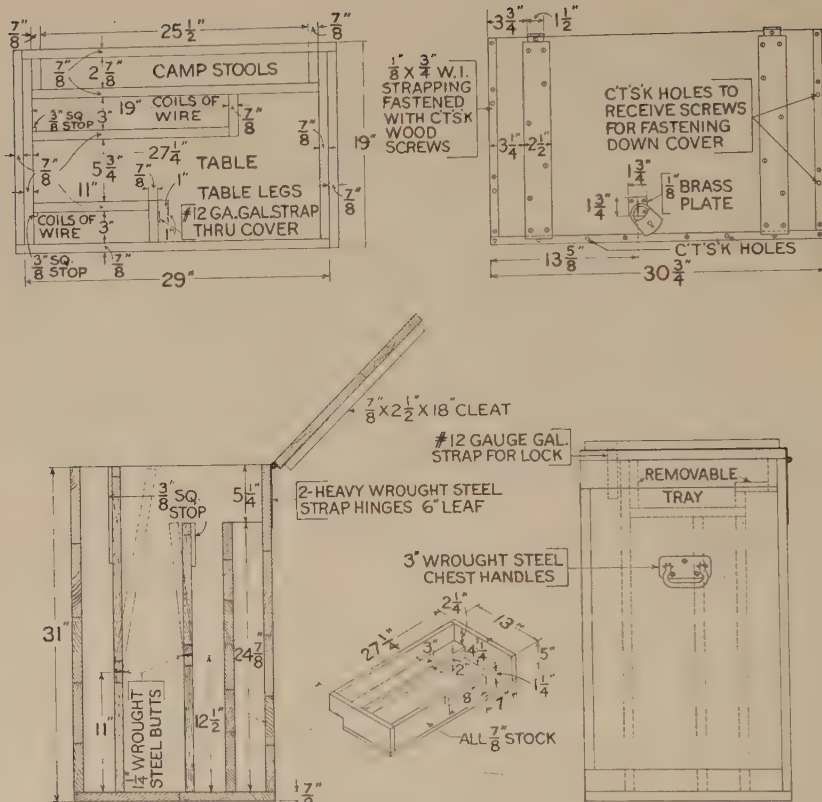


Fig. 53. Working Drawing of Portable Test Table Box
Designed by E. S. Lincoln, Consulting Engineer

ment is equally important as well as a proper place to work when tests are being made.

In Figure 48 is shown a portable test table in use for checking instruments in a large central station. By the use of this table the test engineers have a proper place to work under pleasant working conditions. Furthermore, the test table may be located at any convenient place, provided a 'phone or remote control system is used as shown in Figure 56. Such an outfit provides for the proper transportation of the table and accessory facilities.

As will be seen in Figures 49 and 50, ample space is provided for practically everything except the measuring instruments, which should be transported by hand or in separate cases. The table case is provided with a lock for protection during transportation and when not in use. As will be seen in Fig-

Fig. 54. Portable Test Table, Front View

ures 50 and 51, the table folds up and slides into its containing case. Working drawings are shown in Figures 52 and 53, from which the table may be constructed.

In Figure 54 is shown the table set up ready for use, and in Figure 55 (rear view) is illustrated the method of making the various connections. Where connections are made to the secondaries of current transformers, a very flexible No. 10 duplex conductor, as shown already in Figure 43, is used. This conductor is provided with a lug and fits into binding posts under the

Fig. 55. Portable Test Table, Rear View

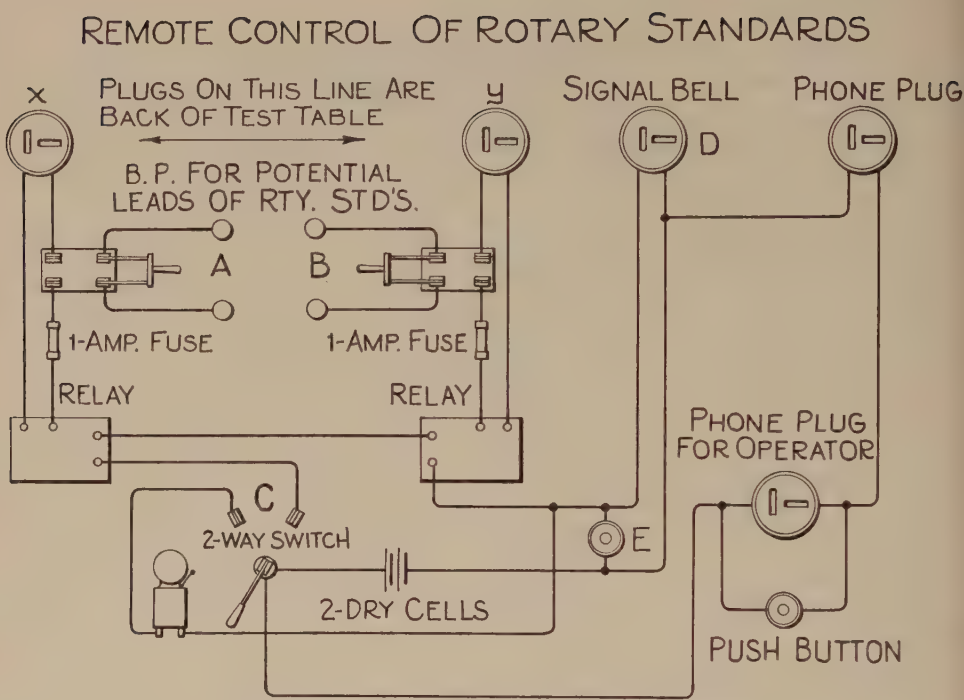


Fig. 56. Diagram of Portable Test Table Connections

table. A loop is made in the conductor across which is placed a spiral spring, which "gives" in case someone carelessly catches in the conductor.

There are many ways for connecting up such an outfit, depending upon local conditions. A few items that have been found convenient will be briefly mentioned. All "potential" binding posts are of the small size and the "current" binding posts of the medium size. All "current" binding posts are provided with short-circuiting switches. Some method of proper lighting is necessary, as often the illumination of the station or sub-station is insufficient for reading instruments.

For rapid and accurate work on switchboard instruments, a remote control and 'phone system are essential, and the one shown in Figure 56 has given very satisfactory results. Two engineers or testers are required, one reading the instruments on the test table and the other reading the meters under test. In checking indicating instruments it is best to use the 'phone, which consists of a headset having two receivers. The operator's set is plugged in on the test table and the second set is plugged into a receptacle on the back of the table, as shown in Figure 56. The 'phones are then ready for use. The

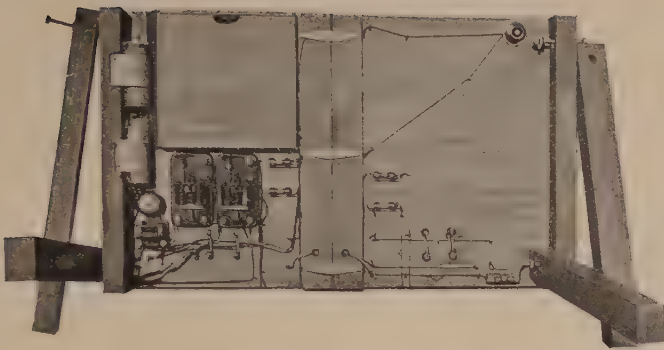


Fig. 57. Bottom of Portable Test Table

push button on the operator's table is used for a signal to "click" the 'phone, which is quicker than a word can be spoken. Often it is not necessary to use the 'phones and a signal bell is substituted, using a code. Such a system is available by connecting the cord and button to plug "D" and placing switch "C" in its left-hand position. (See Figure 56.)

In checking integrating meters some means are necessary for controlling the potential circuits of the rotating standards. This is done by using two common 150-ohm telegraph relays, as shown. If a voltage higher than 110 is used, some other type of relay must be used. These relays have never given the slightest trouble after once being properly adjusted. The potential circuit in use is connected to the test table through the plugs "X" and "Y" and to the rotating standard through binding posts "A" and "B." Switch "C" is then put

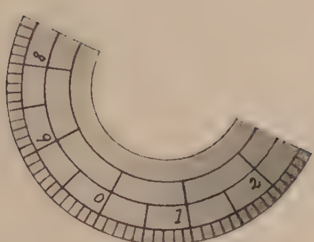


Fig. 58. Portable Meter Scale

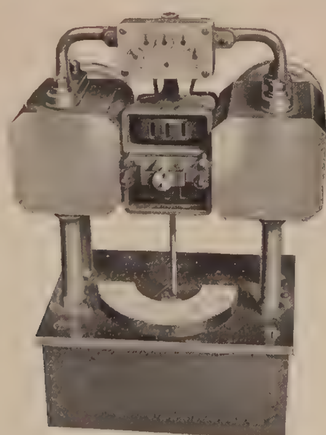


Fig. 59. Portable Meter Scale in Use

in its right-hand position, which disconnects the signal bell and connects in circuit the magnetic circuit of the relays. Push button "E" is used for closing the relay circuit by the operator, if desired. This is necessary for resetting rotating standards not provided with a reset device.

In Figure 57 is shown how the apparatus is arranged under the table.

In addition to the test table, the case contains the following material and supplies, a list of which is placed inside the cover.

The following materials belong in this Tool Box:

1 8″ Monkey wrench.	1 Can of hand cleaning soap.
1 6″ Adjustable "S" wrench.	2 Towels.
1 9″ Screwdriver.	3 Pencils.
1 6″ Screwdriver.	1 Pad of blank paper.
1 Set of small screwdrivers.	Working forms.
1 7″ Cutting plyer.	Cleaning rags.
1 Set of meter inspection tools.	6 Return tags for marking case.
1 Small file.	1 Box of tacks for tags.
1 Small mirror.	2 Insurance blanks, accident.
2 Pairs of electrician's gloves.	1 Portable lamp and cord.
1 Sheet of medium grade sandpaper.	1 Box of matches.
1 Electrician's knife.	1 Flashlight.
1 Roll of splicing compound.	8 1 ampere fuses.
1 Roll of tape.	5 2,200 V. ½ ampere inclosed fuses.
1 Red Cross set.	1 Waterproof cover, 3′ x 5′.
1 Extra dry cell.	1 Extra table light.
6 Potential fuses.	1 Sheet of insulating cloth.
2 Camp stools.	Necessary jumpers and connections.

Where a large number of instruments and meters are to be checked or other tests made in the field, the above test table or a similar one is strongly recommended. The saving in time by its use will more than pay its first cost. The author has used five of these tables for nearly ten years and they are still in good condition, having been shipped all over the country. They have the following advantages:

Provides a proper place for the engineer to work.
Provides a proper place for instruments.
Can be located at some convenient place.
Can be used where conversation cannot be heard.
Saves time, steps and discussion.
Provides a place for accessories under lock and key if necessary.
Provides a proper shipping container.

Inspires confidence in the public and employees by their business-like appearance.

All instruments are in one place under the supervision of the engineer.

Instruments are in proper position for reading.

In checking large watt-hour meters where the revolutions are counted, the small semi-circular disc shown in Figure 58 will be found convenient for accurate readings. This disc is graduated into "hundredths" of a revolution and is used as shown in Figure 59. The side of the disc shown is for use with meters rotating in a counter-clockwise direction, but the figures are in the reverse order on the other side of the disc. In this way the meter under test has a scale similar to that of the rotating standard. The pointer is made of bent wire and slips into the rotating meter shaft.

Chapter VII

PORTABLE ELECTRICAL MEASURING INSTRUMENTS

The subject of electrical measuring instruments would fill a book by itself, and for this reason we are confining this chapter to a few important items relative to those in general use. It is written especially for those who are organizing a laboratory or wish to make additions to existing equipment.

Electrical measuring instruments are made in several grades, some having greater accuracy than others, making them adaptable for various classes of test work.

Those meters working on the Weston permanent magnet movable coil principle are more accurate than any other types which are restricted for use on direct current. Instruments using the "Movable Iron" principle are very popular for A. C. work, but are not as accurate on D. C. as other types. They are, however, well adapted for general use where great precision is not a necessity. Instruments using the electro-dynamometer principle have extreme accuracy on both A. C. and D. C.

Direct Current Voltmeters

For direct current voltage measurements the Weston permanent magnet movable coil instrument will be found best adapted. These instruments are standard for all voltages up to 750, and are made in several models. The

Model 1 instruments have an accuracy of ¼ of 1%, Models 45, 56 and 242 have an accuracy of ½ of 1% and the smaller Model 280 instruments have an accuracy of 1%. One instrument may be provided with several scales if desired, thus increasing its usefulness for general work.

Direct Current Ammeters

A direct current ammeter is in reality a millivoltmeter and the measurement of amperes is derived by "Ohms Law," where $I = \frac{E}{R}$. In other words, a millivoltmeter is used to measure the drop in voltage over a fixed resistance called a "shunt." The instrument itself is calibrated to read amperes, as it requires a predetermined current to cause a difference of potential on each end of the shunt. From this it will be seen that by supplying different shunts practically any value of current may be measured, using one millivoltmeter. These instruments also work on the Weston permanent magnet movable coil principle and may be used with internal or external shunts as desired.

Shunts

Although a shunt is not a measuring instrument in itself, it is such an important accessory that it is mentioned here. Weston shunts are made in two styles, one for switchboard work and the other for precision measure-

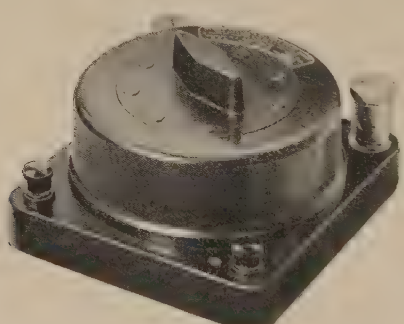


Fig. 60. Rotary Switch Shunt

ments. These shunts are fixed resistances having a very low temperature coefficient. Precision shunts having several ranges are also furnished mounted in a common case. This makes a compact arrangement having a large range of current measurement possible with a single millivoltmeter.

The rotary switch portable precision multiple range shunt, as shown in Figure 60, will be found of great assistance to any standardizing laboratory

on account of its great flexibility of range. It is designed for use with a 50-millivolt, 10-ohm instrument and is accurate within ¼ of 1% when used with a Model 1 Millivoltmeter of that range. This particular shunt has ranges of 1.5, 3, 7.5, 15, 30, 75 and 150 amperes, and a short-circuit position.

Alternating Current Voltmeters

Weston Voltmeters for alternating current are also very flexible and may be obtained in one, two or three ranges and reading up to 750 volts. For general testing work the "movable iron" principle is well adapted. Where greater accuracy is required the electro-dynamometer type should be used, as this type can be checked more accurately with direct current.

Alternating Current Ammeters

Instruments for alternating current may be obtained in either the "movable iron" or the electro-dynamometer type. Weston movable iron ammeters are supplied as a self-contained instrument in sizes up to 500 amperes. These, however, can only be furnished with single scales except in the case of some of the lower ranges. The dynamometer alternating current ammeter is a much more accurate instrument, but this principle only allows a maximum capacity of 20 amperes, on account of the size of the instrument. When higher ranges are desired current transformers must be used. Milliammeters working on this principle will be found very accurate and can be used for work requiring great precision.

Single Phase Wattmeters

Weston wattmeters are electro-dynamometer instruments and may be obtained in ranges up to 100 amperes and 750 volts self-contained. These instruments are very accurate and when provided with two current and two potential ranges will be found very well adapted for service in any standardizing laboratory. They will also withstand considerable overload without injury.

Polyphase Wattmeters

What has been said of single phase wattmeters is true of a polyphase wattmeter, except that the current range is limited to 20 amperes, as these latter instruments contain two single phase elements mechanically connected in one case. The Model 329 Polyphase Wattmeter has one scale and for this reason is easier to read than two single phase instruments.

MISCELLANEOUS INSTRUMENTS

Ohmmeters (Model 1)

These instruments may be obtained with three ranges in a single instrument. They have an accuracy of ¼ of 1% of full scale value and are recommended where many measurements of resistance are to be made. Standard instruments have ranges from 0 to 3,000 ohms. (See Figure 31.)

Megohm Voltmeters (Model 1)

These high resistance voltmeters are recommended for measurement of insulation resistance and for determining voltages where the current required by the voltmeter must be extremely small so as not to disturb the circuit conditions. Resistance of instruments is 1 megohm for highest range and may be obtained with several scales from 0 to 750 volts. They have an accuracy of ¼ of 1%.

Electrolysis Instruments (Models 1 and 56)

These instruments are useful for locating and measuring stray currents in pipes, cables, steel work, etc., and have an accuracy of ¼ of 1% and ½ of 1% respectively. They may be furnished as voltmeters or voltammeters with ranges up to 50 volts and 100 amperes with zero center scales. (See Figure 61.)

Galvanometers (Model 440)

A high-grade galvanometer is a necessity in the larger laboratories. This type of instrument has in the past been almost entirely confined to laboratory work and could be used only in places that were practically free from vibration. Formerly such instruments were extremely delicate, requiring great care in their use. A very convenient high-grade portable galvanometer, made especially for use with Wheatstone Bridges, low resistance potentiometers, both high and low resistance testing, thermo-couple work, etc., is shown in Figure 62. This galvanometer may be treated practically the same as any sensitive portable measuring instrument. The resistance of the movable coil may be obtained from 3.5 to 150 ohms, and sensitivities as high as one millimeter for 0.25 microampere.

Relays (Model 30)

In some special tests and research investigations an accurate direct current contact-making relay is often required. For this purpose the Weston relay has been developed for closing a local circuit for any desired currents and voltages within very definite limits. These may be obtained in three styles, galvanometer, voltmeter and current relays. (See Figure 63.)

Fig. 61. Model I Electrolysis Volt-Ammeter

Fig. 62. Model 440
Galvanometer

Speed Indicators or Tachometers (Model 44)

Where accurate measurements of speed are to be made, the Model 44 Magneto, illustrated in Figure 64, will be found well adapted. This magneto may be connected to an accurate voltmeter and speed indications obtained at a considerable distance from the machinery where the speed measurement is being made. The accuracy of this magneto is well within 1%, its errors being in addition to those of the measuring instrument with which it is connected. A speed of 1,000 R. P. M. will generate 6 volts, the voltage being directly proportional to the speed.

Standard Cells (Model 4)

The Weston Cadmium Cells are constructed in two forms, the normal or saturated cell and the unsaturated cell. The normal cell is seldom used for commercial purposes for the reason that it is slightly affected by temperature, but is maintained by the National Laboratories throughout the world as the standard of electromotive force. The Weston Standard Cell is of the unsaturated type, has no temperature error, and is used for all commercial purposes. When used in connection with potentiometers, three cells should be available, keeping one as an absolute standard for comparison at frequent intervals.

It is important that standard cells should not be subjected to a lower temperature than 4° C. or higher than 40° C. These cells should never be connected in a circuit that will allow more than .0001 of an ampere to pass

Fig. 63. Model 30 Relay

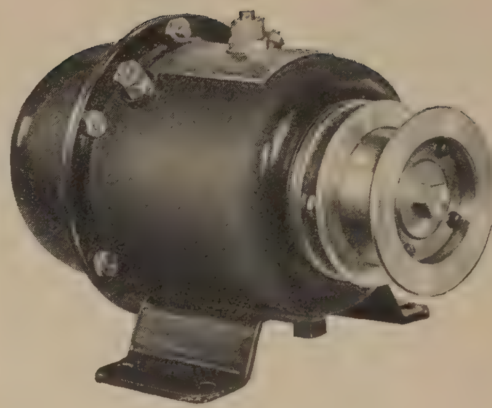


Fig. 64. Model 44 Magneto

through the cell. The cell is designed for use in connection with tests or calibration when using the zero or "null" method of establishing potential differences. In other words, it is used when no current is drawn from the cell when the actual balance occurs. It is very desirable to protect the cells by a series resistance of at least 10,000 ohms until the balance has been practically established. Many cells have been ruined as standards by connecting them to an ordinary voltmeter in attempting to measure their voltage. One of these cells is illustrated in Figure 65.

Current Transformers

Weston current transformers for use with portable testing instruments are designed to cover a wide range of measurement and their accuracy makes them well adapted for standardizing or general laboratory work. The function of a current transformer is to transform the line current in an exact ratio to a small value that may be accommodated by the current coils of ammeters or wattmeters. Bear in mind that most portable instruments are so calibrated that the actual reading must be multiplied by the ratio of transformation in order to get the true result. Switchboard instruments are usually provided with scales reading primary values. Current transformers are, therefore, quite similar to regular distributing transformers, but are used for a different purpose.

A reference to Figure 66 shows the primary and secondary windings of a current transformer. The secondary winding is connected in series with the ammeter or current coils of the wattmeter. All the line, or primary, current passes through the primary coil of the transformer, and transformers are generally designed so that when the primary is fully loaded to its rated capacity, the secondary will have induced in it a value of 5 amperes. This is standard practice and therefore when wattmeters or ammeters are to be used with transformers they are supplied with 5-ampere field or current coils. The primary and secondary windings are carefully insulated so that the transformers may be used on voltages that might otherwise endanger the instrument or operator.

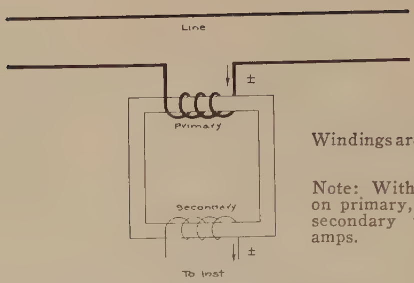
From what has been said, it will be understood that a transformer with a ratio of 50 to 1 is calculated to permit 250 amperes to flow through the primary and induce 5 amperes in the secondary.

Current transformers are therefore a necessity when large currents or high potentials are in use. Even on low voltages they are very desirable because heavy conductors can be run to the transformer, which may be placed on the floor, while the connections to the instrument proper, which may be conveniently mounted on a table at any desired distance, may be relatively small wires.

Fig. 65. Model 4 Standard Cell

Figure 67 shows a Model 312 Weston Current Transformer having three ranges, which are made in the following combinations: 10-20-40, 25-50-100, 50-100-200 amperes.

Figure 69-a shows a Model 461 Current Transformer. It has three self-contained ranges 10, 20 and 40 amperes, and a "hole" through which conductors can be passed by the user to obtain ranges up to 800 amperes. It has a weight of 6¼ pounds, and a capacity of 5 volt amperes. It is designed for use with an ammeter, wattmeter, and a power factor meter for field work such as motor testing in industrial plants, etc. For measuring greater currents up to 2,400 amperes, the Weston inserted primary type, Model 313 Current Transformer, is used, as shown in Figure 68. The one precaution that must be taken in using current transformers is the necessity that no current pass through the primary when the secondary circuit is "open." Weston current transformers are provided with a short-circuiting switch on



Ratio=Rated primary current divided by 5. Example: transformer rated at 100 amps. has ratio and multiplying factor of 20 as $100/5=20$ & for an 800 amp. trans. 160 as $800/5=160$. ∴ Every amp. on secondary=160 on primary.

Fig. 66. Arrangement of Windings in Current Transformer

the secondary side, which should remain closed until all secondary connections are made, but opened before the circuit is alive, and reclosed when the test has been completed. Opening the secondary when the primary is alive will produce a high voltage, which may be dangerous to the operator and will affect the accuracy of the readings. If an open circuit in the secondary accidentally occurs while the transformer is connected to line, the original accuracy may be temporarily impaired, but may subsequently be restored by passing an alternating current of two or three amperes (at any commercial frequency) through the secondary, and very gradually reducing the current to zero.

In making connections between an instrument and current transformers do not use wire of smaller size than No. 14 B. & S. gauge, and this for short stretches of a few feet only. For long runs of fifteen feet or over use a wire equal to No. 10 B. & S. gauge in size.

When making a test, portable current transformers should include instruments only, hence they should not be connected with other apparatus in the secondary circuit.

Current transformers when checked should have their secondaries connected with the secondary burden with which they will be used.

Be very careful of all secondary connections to make certain that there is no possibility of the circuit being broken when the current is on. Be sure to understand and select the proper ratio when making a test and do not forget that unless the instrument is specially calibrated to include the transformer primary rating, the multiplying factor must be used in all calculations. Otherwise the readings will be worthless. For example: When using a current transformer having a ratio of 10 to 1, be sure to multiply all instrument readings by 10, as the current being measured in the primary is 10 times greater than that passing through the meter.

Fig. 67. Model 312 Current Transformer

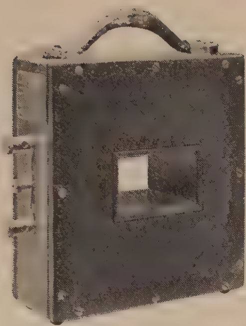


Fig. 68. Model 313 Current Transformer

Usually switchboard meters have their scales marked so as to show the current passing through the primary of the current transformers, and in such cases a multiplying factor is not necessary.

Figure 69 illustrates one of the Weston current transformers known as the "bus-bar" or inserted primary type arranged with one, two and four conductors through the primary winding, which results in respective ranges, 800, 400 or 200 amperes to 5 amperes, or ratios of 160-80-40 to 1. Note that when the conductor passes around the opposite side of the transformer that its direction of winding must be changed in order that all parts of the conductor starting from one end shall pass through the hole in the same direction. (See 200 to 5 ratio at bottom of Figure 69 using 4 conductors.) Current transformers are subjected to much greater phase angle errors than potential transformers and at low power factors these errors are more pronounced. Ammeters having a five-ampere winding should be used, as those with smaller windings have greater resistance and larger windings than five amperes involve scales that are difficult to read. Direct current should never be passed through a current transformer.

Potential Transformers

The potential transformer works on the same principle as any power or distributing transformer but its capacity is comparatively small and its ratio of transformation is much more accurate. The object of this transformer is to reduce a high tension voltage to a low value so that it can be used in the instrument conveniently. It would be unwise to apply 2,200 or more volts

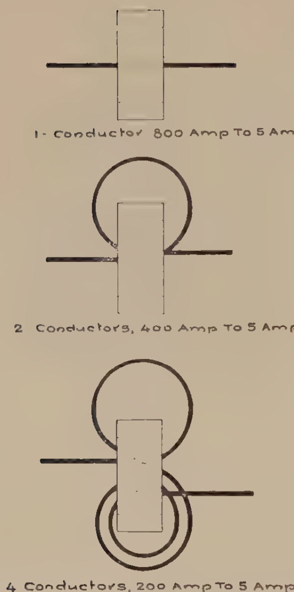


Fig. 69. Transformation Ratio of Inserted Type Current Transformer

Fig. 69a. Model 461 Current Transformer

directly to an instrument and the use of a multiplier or series resistor does not relieve the operator from the danger of possible shock.

A potential transformer and its connections are shown in Figure 70. Potential transformers are built for standard line voltages on the primary side and the secondaries are arranged for 110 volts normal and 150 volts maximum so that they may be used with instruments having potential coils and scales of 0 to 150 volts. In using a potential transformer it is very essential that no mistake be made between the primary and secondary windings. For this reason be sure to check all connections before turning on the current.

Portable potential transformers have a capacity of from fifteen to twenty-five volt-amperes and for this reason they should be used for no other purpose except for voltage coils of wattmeters, voltmeters, frequency meters and power factor meters; that is, they should be restricted to secondary burdens within their capacity, if the highest accuracy is desired.

As Weston instruments require a very small amount of power for their operation, Weston transformers will carry the combined burdens of the instruments referred to with high accuracy.

Never leave portable potential transformers in circuit when not in use because a severe surge might occur and injure the windings.

When two or more potential transformers are used on the same system and it is desired to know their relative polarity, this may be obtained by connecting the secondaries in series and exciting the primaries with line voltage or less. If the secondary voltage on the transformers is double that of the single transformer they are in series but if there is practically no voltage existing between them they are then in opposition.

All Weston instrument transformers are marked for proper polarity with a ± on the primary and a corresponding ± on the secondary. This marking indicates that if at any instant current enters the ± primary terminals, current is leaving the ± secondary terminal.

When using potential transformers do not neglect to multiply the instrument readings by the ratio of transformers. For instance, a voltmeter reading 105 volts when connected with a 2,200 to 110-volt potential transformer denotes a potential of 2,100 volts on the primary side. The ratio is 20 to 1, which means that every 20 volts on the line equals one volt on the instrument.

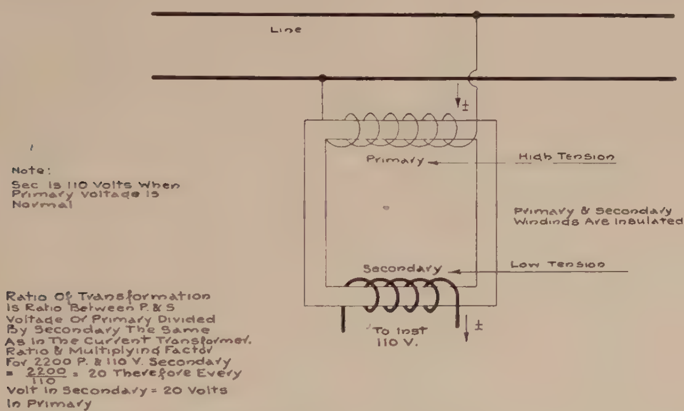


Fig. 70. Arrangement of Windings in Potential Transformer

Chapter VIII

THE PROPER SELECTION OF PORTABLE MEASURING INSTRUMENTS

The selection of the proper instruments for central station laboratories is a subject that would lead afar if we attempted to cover each requirement that has come to our attention in this field of work. But we have selected a few

examples of what have proven to be the most satisfactory testing sets in average laboratories and we believe our recommendations will meet the requirements of many of our readers who may have occasion to buy for the first time or who find it desirable to add to existing equipment.

Indicating types of instruments are more needed in laboratory work because they give instantaneous readings of the electrical quantities with which it is necessary to deal in testing equipment, checking investigations, etc. When it is desired to create a record of the performance of a piece of equipment over a period of time, say a day, week, or month, graphic meters, which record the fluctuations on a chart, will be found to be a valuable adjunct.

Primary Standards

The question as to whether or not a central station laboratory should be provided with primary standards depends upon two factors aside from the expense involved. First, the size of the company, which determines the number of meters in the laboratory which require standardizing; second, the location of the laboratory in reference to other laboratories where primary standards are already maintained. When a laboratory is located near some of our large colleges or universities, arrangements may be made for the use of their primary standard facilities. Furthermore, a small laboratory can often make arrangements for checking its secondary standards in the laboratories of a large company in its vicinity. If, however, a large number of portable instruments are in use, considerable saving of time can be made by owning the necessary primary standards.

Primary standards are not listed, as these have been mentioned in Chapter II and are quite special, being necessary only in the larger laboratories.

Secondary Standards

For the actual checking of measuring instruments, the use of secondary standards is preferred. Calibrations and checking by reference to secondary standards are much easier to make and their use is much less complicated than checking direct with primary standards. These standards are large semi-portable measuring instruments having a long scale and are easily read with great accuracy. They form the connecting link between portable and switchboard instruments in the laboratory and the precision primary standards previously mentioned. Secondary standards are used by practically all of the large operating companies and form the basic standard in the majority of laboratories. Where primary standards are not available, these instruments may be checked by sending them to the manufacturer or to the Bureau of Standards in Washington.

Fig. 71. Model 5 Voltmeter

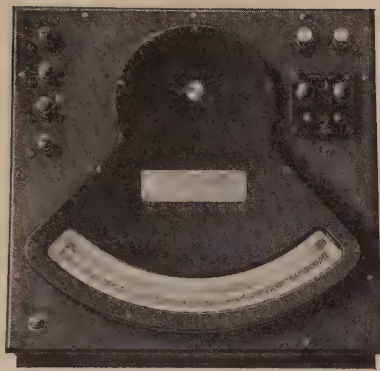


Fig. 72. Model 326 Wattmeter

The following list of secondary standards is recommended for any electrical standardizing laboratory:

Volts—Direct current—Model 5.

Volts—Alternating current—Model 326.

Amperes—Direct current—Model 5.

Amperes—Alternating current—Model 326.

Watts—Alternating current and direct current—Model 326.

The above instruments have scales 12″ long and are accurate to 1/10 of 1%. In Figure 71 is shown a Model 5 Voltmeter and in Figure 72 a Model 326 Single Phase Wattmeter.

The proper selection of these standard instruments will depend upon the portable instruments and their ranges that constitute the laboratory equipment.

Suggested Recommendations

The following recommendations relate to indicating instruments:

The first point to be determined is whether alternating current or direct current instruments or both are needed. Then a review of services required of the laboratory will enable an engineer to roughly ascertain the preferable scales or ranges of the instruments and accessories. It is quite satisfactory in small laboratories to use some of the small size Weston instruments, shown in Figure 73, but in the larger laboratories we recommend larger and somewhat more accurate instruments, shown in Figure 74. Where heavy currents are handled, it is necessary to also have current transformers and for voltages of over 750 the use of both current and potential transformers is necessary. Voltmeters are very easy to select. Any type can be supplied with a double range and thus provide for high as well as low voltage tests.

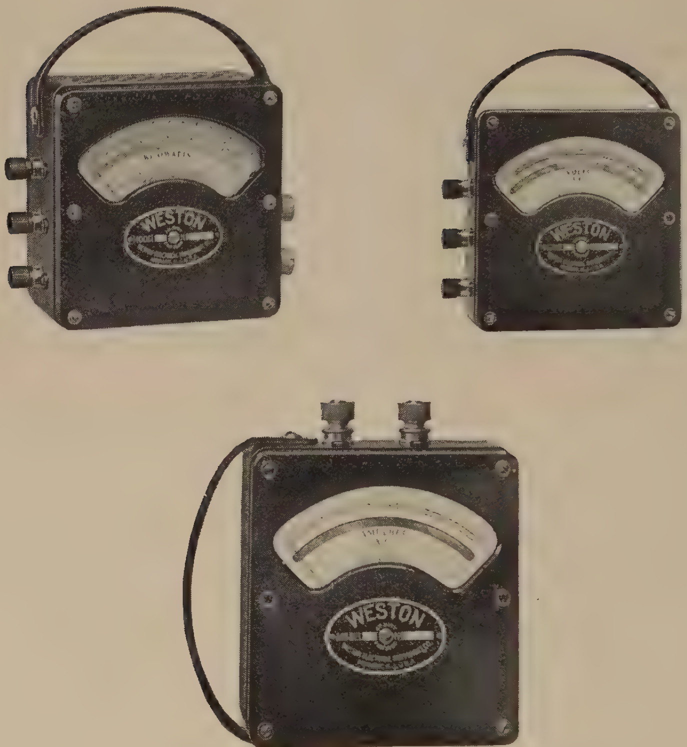


Fig. 73. Group of Weston Junior Portable A. C. Instruments, Models 432 and 433

The majority of central station laboratories require only alternating current instruments but many of the larger companies maintain a direct current distributing system, making it necessary for the laboratory to also possess direct current instruments. Where an electric railway is operated by the utility, direct current instruments must be available. Direct current instruments are not listed as a complete outfit, but a few have been mentioned to cover general testing only. In the following paragraphs there are suggestions covering the instruments that are necessary for the operation of systems serving a few hundred to many thousand customers. This suggested list is for general operating conditions and does not provide for any research or special investigations. Furthermore, the number of rotating standards suggested is only general, as the actual number required will depend upon how extensively the company tests its customers' meters in the field.

It is difficult to list a particular set of measuring instruments for each class of operating company and for this reason the following recommendations are general, and are based upon the number of customers' watt-hour meters it has in service.

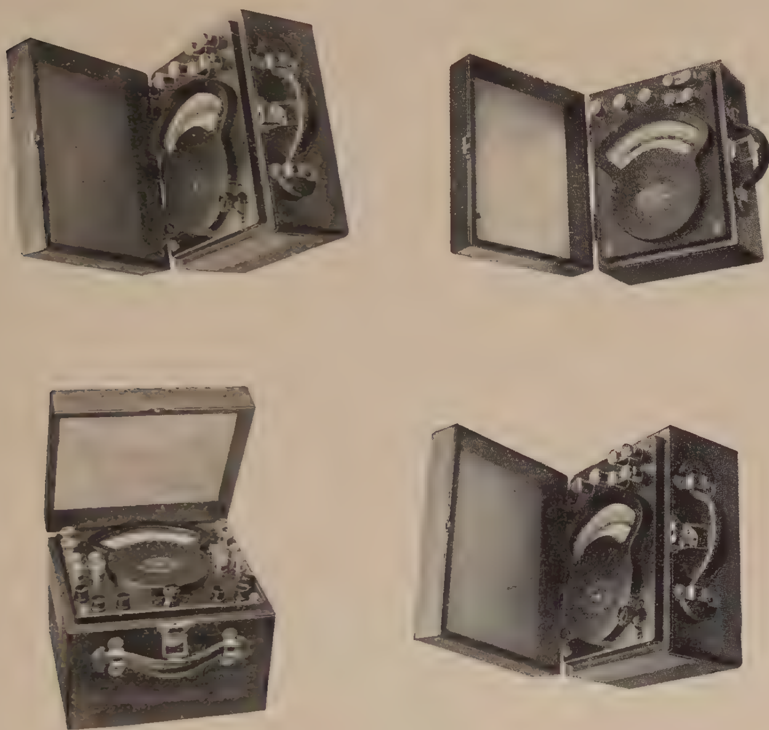


Fig. 74. Group of Weston Portable A. C. Instruments,
Models 310, 329, 341, 370

Small Companies Having Only a Few Hundred Customers' Meters

1 Model 155 Voltmeter, reading 150-300.

1 Model 155 Ammeter, reading 5-10 or 2.5-5.

3 Watt-hour Meters arranged as standards.

By means of these watt-hour meters arranged as standards, any customer's meter may be checked by bringing it into the laboratory, or a rotating standard may be borrowed and all meters checked as occasion demands.

One Thousand Five Hundred Customers' Meters

1 Model 155 Voltmeter, reading 150-300.
1 Model 433 Voltmeter, reading 150-300.
1 Model 155 Ammeter, reading 5-10 or 2.5-5.
1 Model 432 Wattmeter with 150-300-volt winding and 5-ampere current coil.
1 Model 312 Current Transformer, 10-20-40 amperes to 5 amperes.
1 Model 311 Potential Transformer, 1,100-2,200 to 110 volts.
2 Rotating Standards.
3 Watt-hour Meters arranged as standards.

Five Thousand Customers' Watt-hour Meters

1 Model 341 Voltmeter, 150-300.
1 Model 155 Voltmeter, reading 150-300.
1 Model 370 Ammeter, 5-10 or 2.5-5.
1 Model 155 Ammeter, reading 5-10 or 2.5-5.
2 Model 312 Current Transformers, 10-20-40 amperes to 5 amperes.
2 Model 312 Current Transformers, 50-100-200 amperes to 5 amperes.
2 Model 311 Potential Transformers, 1,100-2,200 to 110 volts.
2 Model 432 Wattmeters, 150-300 volts, 5 amperes.
3 Rotating Standards.
3 Watt-hour Meters arranged as standards.

Ten Thousand Customers' Watt-hour Meters

1 Model 326 Laboratory Standard Voltmeter and Multiplier for 75-150-300-750 volts.
1 Model 326 Laboratory Standard Wattmeter and Multiplier for 75-150-300-750 volts, 2.5 and 5 amperes.
1 Model 326 Laboratory Standard Ammeter, 0-2.5 and 0-5 amperes.
1 Model 341 Voltmeter reading 0-150 and 0-300 volts.
1 Model 155 Voltmeter, reading 0-150 and 0-300 volts.
1 Model 155 Voltmeter, reading 0-150 and 0-600 volts.
2 Model 155 Ammeters, one reading 0-5 and 0-10 amperes and the other 0-2.5 and 0-5 amperes.
2 Model 155 Ammeters, reading 0-50 amperes.
2 Model 312 Current Transformers, 10-20-40 amperes to 5 amperes.
2 Model 311 Potential Transformers, 1,100-2,200 to 110 volts.
2 Model 432 Wattmeters, 150-300 volts, 5 amperes.
3 Watt-hour Meters arranged as standards.

1 Model 45 Voltmeter, 15-150-300 volts (direct current).
1 Model 45 Ammeter, 0-15 and 0-150 amperes (direct current).
4 Rotating Standards.

Twenty-five Thousand Customers' Watt-hour Meters

Secondary Standards, as listed under "Ten Thousand Meters."
2 Model 341 Voltmeters, reading 150-300 volts.
1 Model 341 Multiplier, 5 to 1 for 750 volts.
2 Model 155 Voltmeters, reading 150-300 volts.
1 Model 155 Voltmeter, reading 150-600 volts.
1 Model 433 Voltmeter, reading 150-300 volts.
2 Model 370 Ammeters, reading 0-2.5 and 0-5 amperes.
4 Model 155 Ammeters, reading 0-5 and 0-10 amperes or 0-2.5 and 0-5 amperes.
2 Model 155 Ammeters, reading 0-50 amperes.
2 Model 155 Ammeters, reading 0-200 amperes.
2 Model 461 Current Transformers, 10-20-40 and 800 amperes to 5 amperes.
2 Model 312 Current Transformers, 50-100-200 amperes to 5 amperes.
2 Model 311 Potential Transformers, 1,100-2,200 to 110 volts.
1 Model 329 Polyphase Wattmeter, 150-300 volts and 5 and 10 amperes.
2 Model 310 Single Phase Wattmeters, 150-300 volts. One meter 2.5 and 5 amperes, other 5 and 10 amperes.
2 Model 432 Wattmeters, 150-300 volts, 5 amperes.
1 Model 339 Frequency Meter, 110-220 volts.
1 Model 1 Direct Reading Ohmmeter, 0-300-1,500-3,000 ohms.
1 Model 44 Tachometer.
1 Model 440 Galvanometer.
1 Model 45 Voltmeter, 15-150-300.
1 Model 45 Millivoltmeter with external shunts, 5-10-50 and 100 amperes.
6 Rotating Standards.

More Than Twenty-five Thousand Customers' Watt-hour Meters

Complete set of Primary and Secondary Standards.

As the larger operating companies already have very extensive laboratories, it is not necessary to suggest instruments required for their use. All of these laboratories are well supplied with Weston instruments. However, as the

Weston Corporation is adding from time to time other instruments that will be found necessary to all laboratories, they will be very glad to assist all laboratories in any way possible in the selection of proper laboratory facilities.

General Notes

The foregoing suggestions are subject to some changes, depending upon the operating voltages and secondary power voltages.

In all cases we recommend the use of leather containers for instruments used outside the laboratory. The protection given the instrument will more than pay for the cost of the case.

All laboratories should add instruments to their equipment from time to time in order to extend the service rendered and to keep up with the growth of the company.

The number of instruments required by a laboratory will also be determined by the territory reached by its lines. A company that is compact and supplies service within a few miles of the laboratory will not require as many instruments as a system covering a large territory with many sub-stations. In this latter case more instruments will be required on account of the amount of time consumed in transporting instruments from one station to another.

While it is possible to purchase instruments with many ranges, it must be remembered that such a method ties up the work if all scales are on one meter. It is cheaper to have two instruments than to delay men in their work.

Another point in determining the number of instruments necessary is in the division of the work. Some instruments should only be used in the laboratory by the engineers in charge. Another set should be available for the trouble department. Still other instruments should be available for loan purposes to customers, other operating companies, etc., if such practice is in vogue. Either the laboratory instruments or a special set should be used for checking in the field.

The ranges of direct current instruments may be greatly varied by the use of multipliers and shunts. Alternating current instruments may have extended ranges by the use of multipliers or in most cases by current and potential transformers.

The service supplied by the company will have a direct bearing on the scales of the instruments. A company supplying all lighting customers will require different scales than one supplying power only. As a general rule both power and lighting service is supplied, making double or triple range instruments a necessity.

Suggested Instruments for Research and Investigations

Model 372 Portable Direct Reading Microfaradmeters.

With ranges from .05 to 10 microfarads for use on 100 to 130 volts, 50 or 60 cycles.

Lower ranges are available for use on 200 to 250-volt circuits and for 500-cycle frequency.

Model 1 Millivoltmeters, ranges 0 to 500 millivolts.

Model 1 Milliammeters, with ranges from 1.5 to 1,500 milliamperes.

Model 1 Microammeters, ranges 300 to 1,500 microamperes.

Model 322 Microammeters, ranges 50 to 300 microamperes.

Model 322 Millivoltmeters, ranges 1 to 100 millivolts.

Model 440 Galvanometers.

Model 30 Relays.

Model 1 Ohmmeters, with ranges up to 3,000 ohms.

Model 1 Megohm Voltmeters.

Special Instruments for Electrolytic Investigations.

WESTON ALTERNATING CURRENT INSTRUMENTS

PORTABLE

Accuracy		Ammeter	Volt-Meter	Watt-meter Single Phase	Watt-meter Poly-Phase	Thermo Ammeter	Milli-Ammeter	Micro-farad-meter
1/10 of 1%	Model Movement Capacity	326 D. 10 amps.	326 D. 300 volts	326 D. 6 k. w.				
¼ of 1%	Model Movement Capacity	370 D. 10 amps.	341 D. 750 volts	310 D. 75 k. w.			370 D. *15 m.a.	
½ of 1%	Model Movement Capacity	155 M. I. 500 amps.	155 M. I. 750 volts		329 D. 30 k. w.	412 50 amps.	155 M. I. *75 m.a.	372 *0.003 m.f.
1%	Model Movement Capacity	433 M. I. 50 amps.	433 M. I. 300 volts	432 D. 15 k. w.			433 M. I. *75 m.a.	

Explanation of Symbols and Terms.

M. I.—Movable Iron or Soft Iron Movement.

D.—Electrodynamometer Movement.

Capacity—Indicates maximum self-contained ranges.

*Minimum Range.

WESTON PORTABLE INSTRUMENT TRANSFORMERS

POTENTIAL TRANSFORMERS

Model	Type	Maximum Primary	Secondary	Frequency	Capacity Volt-Amperes
311	S. C.	6600-4400 3300-2200 volts	110 volts	25-133 cycles	15
457	S. C.	2200 volts	110 volts	25-133 cycles	25

CURRENT TRANSFORMERS

312	S. C.	200 amperes	5 amperes	25-133 cycles	25
313	I. P.	2400 amperes	5 amperes	25-133 cycles	25
461	I. P. S. C.	800 amperes	5 amperes	25-133 cycles	5

S. C.—Self-contained. I. P.—Inserted Primary.

SUGGESTIONS FOR RECOMMENDING DIRECT CURRENT PORTABLE OR SEMI-PORTABLE INSTRUMENTS

Use	Model	Accuracy
For Reference or Secondary Standards	5	1/10 of 1%
For Certified Tests and Precision Work	1	¼ of 1%
For General Testing, Inside and Outside	45-56-242	½ of 1%
For Convenient Portability and Testing not to exceed 150 volts and 30 amperes self-contained	280	1%

ALTERNATING CURRENT PORTABLE OR SEMI-PORTABLE INSTRUMENTS

For Reference or Secondary Standards	326	1/10 of 1%
For Certified Tests and Precision Work	310-341-370 329	¼ of 1% ½ of 1%
For General Testing, Inside and Outside for Industrial and Commercial Purposes	155 432-433	½ of 1% 1%

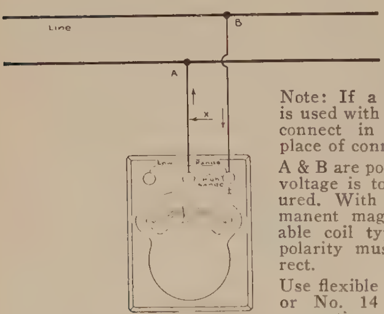
Chapter IX

INSTRUMENT CONNECTIONS

The name of an instrument indicates the electrical quantity it will measure.

In using electrical measuring instruments for testing, it is absolutely necessary to understand just how they should be connected into the various circuits.

We believe this subject of "connections" will be easily understood by reference to the actual working diagrams which are listed in the following pages, and direct attention to the following group of connections, which should be understood *before proceeding with any testing work:*



Note: If a multiplier is used with voltmeter, connect in series in place of connection X.

A & B are points where voltage is to be measured. With D.C. (permanent magnet, movable coil type) meter polarity must be correct.

Use flexible lamp cord or No. 14 wire for connections.

Fig. 75. A.C. or D.C. Voltmeter without Multiplier for Circuits Up to 750 Volts

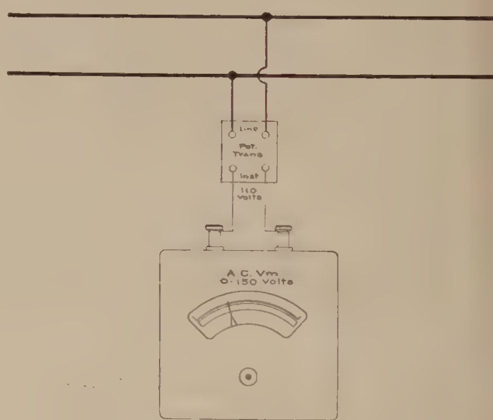


Fig. 76. A.C. Voltmeter with Potential Transformer

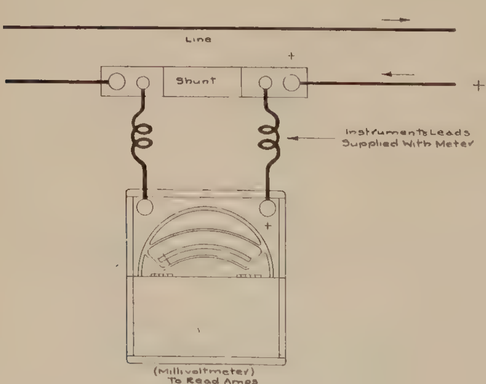


Fig. 77. D.C. Ammeter With External Shunt

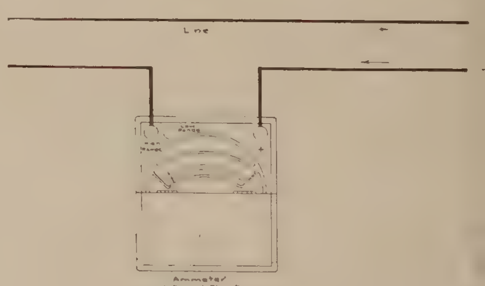


Fig. 78. D.C. Ammeter With Internal Shunt

When using ammeters having external shunts, be sure to use the proper leads supplied with the ammeter, as other leads may cause errors by changing the resistance of the instrument circuit.

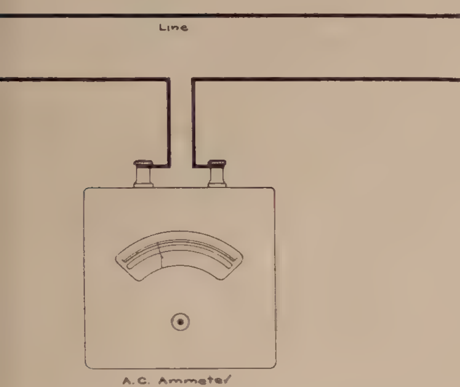
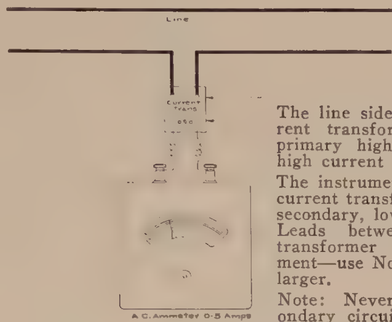


Fig. 79. A.C. Ammeter Connected Directly in Circuit



The line side of the current transformer is the primary high voltage or high current or both.

The instrument side of the current transformer is the secondary, low current. Leads between current transformer and instrument—use No. 14 wire or larger.

Note: Never open secondary circuit when current is on. Close switch on current transformer if instruments are to be disconnected from circuit, and when test is completed. If an open circuit in the secondary accidentally occurs, while the transformer is connected to line, the original accuracy can be restored by passing an alternating current of two or three amperes (at any commercial frequency) through the secondary, and very gradually reducing the current to zero.

Fig. 80. A.C. Ammeter Thru Current Transformer

Weston Wattmeters

As the wattmeter is so frequently used in tests or investigations of electric equipment in alternating current systems, the proper method of connecting them in circuit should next be studied.

Weston Wattmeters are extremely accurate and, having large overload capacities, are very flexible. They are made in three models, two single-phase and one polyphase (two or three phase). Figure 81 shows the Model 432 Single-Phase Wattmeter of the small size and Figure 82 the Model 310 Single-Phase Wattmeter. Figure 83 illustrates the Model 329 Wattmeter, which may be used on single, two or three phase circuits and on D. C. circuits.

Wattmeter Connection Diagrams are as follows:

Instruments Model Nos. 310 and 432, Single-Phase.

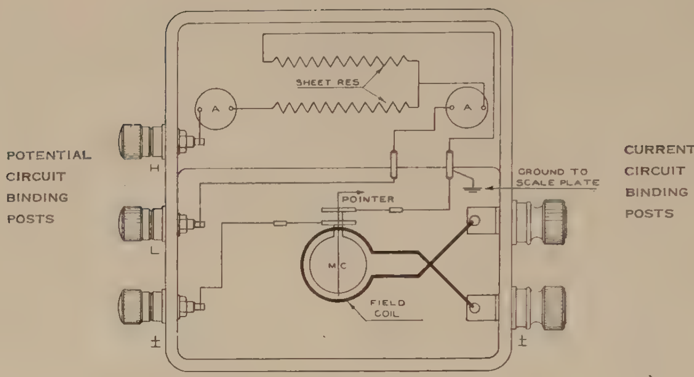


Fig. 81. Model 432 Single Phase Wattmeter

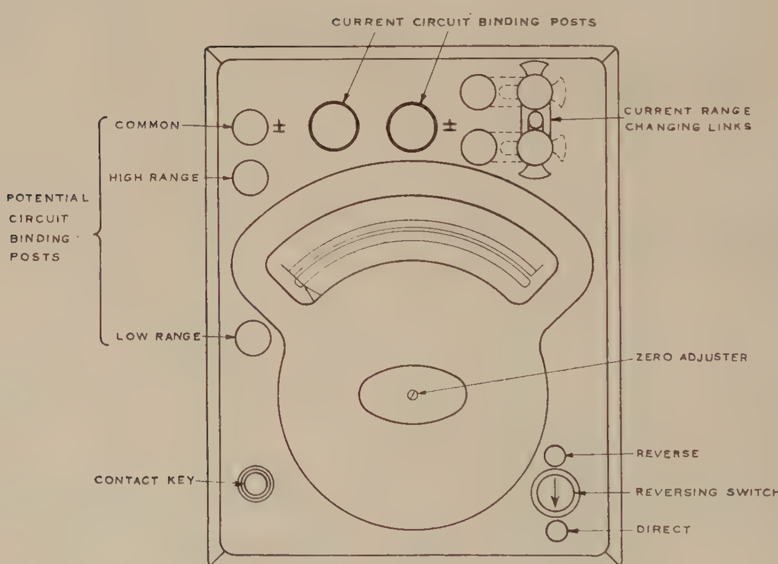


Fig. 82. Model 310 Single Phase Wattmeter

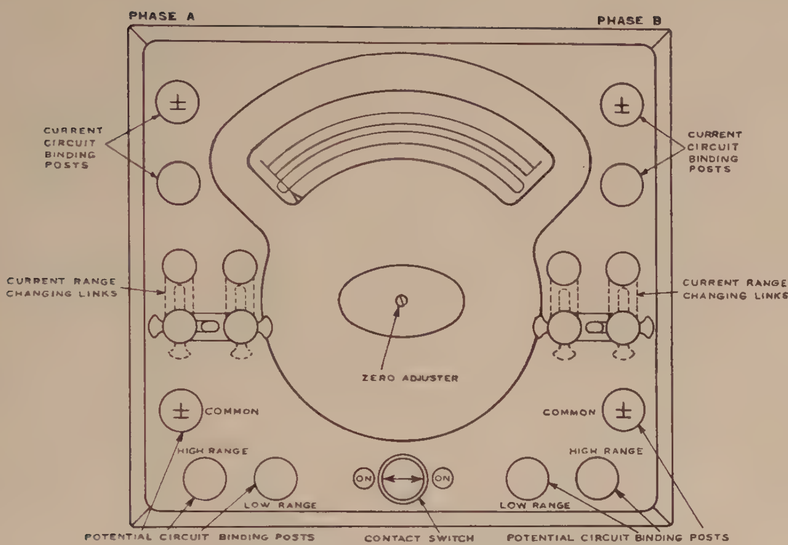


Fig. 83. Weston Model 329 Polyphase Wattmeter

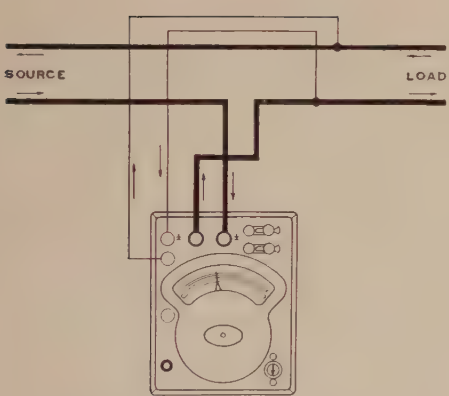


Fig. 84. Single Phase Wattmeter connected directly to line

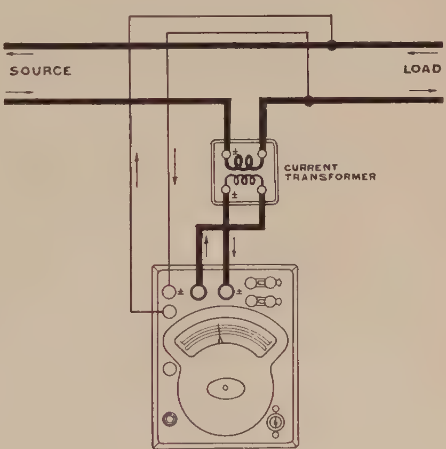


Fig. 85. Single Phase Wattmeter with potential circuit connected directly to line and with current coils connected through current transformer.

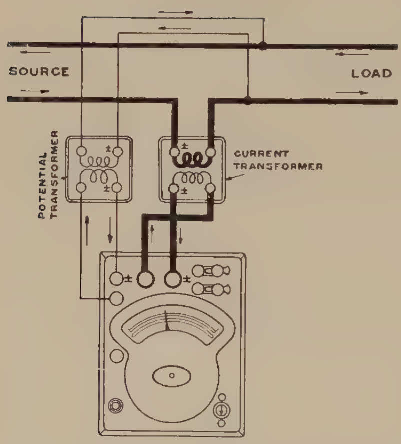


Fig. 86. Single Phase Wattmeter with both current and potential transformer for measuring power on high voltage circuits.

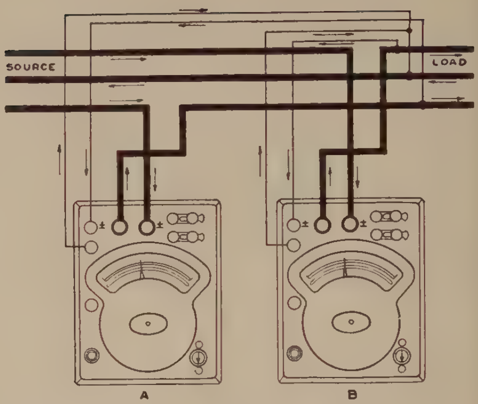


Fig. 87. Two Wattmeter method for measuring D.C. or single phase power on 3-wire systems. (Note: This same connection can be used for measuring power on either 2 or 3-phase, 3-wire systems.)

The Following Diagrams Are for Use With Weston Model 329 Polyphase Wattmeter

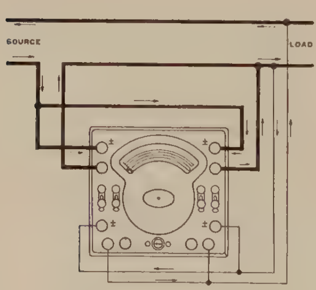


Fig. 88. Measuring power on single phase and direct current circuits when current coils of wattmeter are connected in multiple, thus obtaining a total current capacity equal to the capacity of both coils of the instrument.

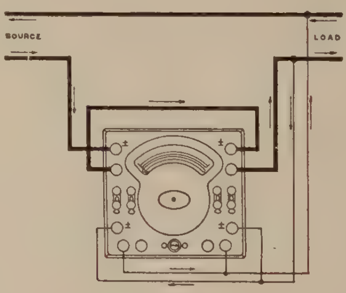


Fig. 89. Power measurement for direct and single phase current with current coils in series. Total current should not exceed the capacity of each individual coil. It is to be used for low readings and under these conditions the values on the scale should be multiplied by ½.

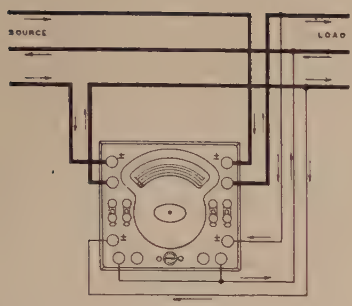


Fig. 90. Power measurement for direct current three-wire, single phase three-wire, two and three-phase alternating current, three-wire circuits.

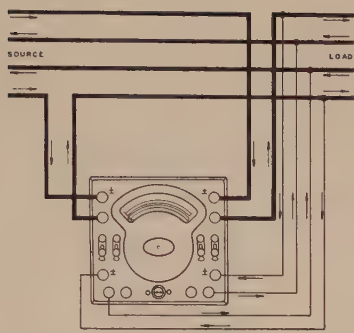


Fig. 91. Power measurement for two-phase, four-wire alternating current.

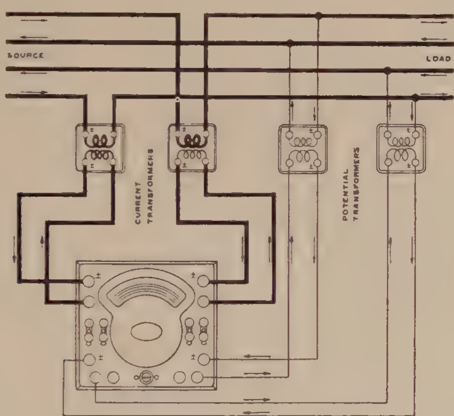


Fig. 92. Power measurement for two-phase, four-wire circuit, using both current and potential transformers.

It will be noticed in the wattmeter connection diagrams that the potential circuits are connected on the load side of the wattmeter current coils. With these connections the actual load voltage is impressed directly on the wattmeter circuit, but the wattmeter indication also includes the power consumed by the wattmeter potential circuit, amounting to only 2 or 3 watts, which is so small that it can be neglected in most measurements. If corrections for this wattmeter loss must be made, it is much more easily determined than the loss in the current coils, which would be included in the wattmeter indications if the potential connections had been made on the source side of the wattmeter current coils.

In the event that the wattmeter loss of two or three watts can not be neglected in comparison to the power being measured, then the simplest method for determining this loss is to open the load circuit and read the instrument, which then indicates directly the wattmeter loss.

The size of conductor to use in the above connections will depend upon the current to be measured. For voltmeters or the potential circuit of wattmeters No. 14 B. & S. gauge wire or twisted lamp cord No. 18 will answer.

In Table 2, page 145, will be found the carrying capacities of copper wire and when additional connections are required, the proper size may be determined. When short lengths are used (20 feet or less) the current values given in the table may be increased by 33 1/3% where the conductors are exposed to free air and not in coils. The increase of current will not injure the insulation of the conductor. A long conductor should not be overloaded, as in such cases the voltage drop might introduce errors into the test.

Chapter X

ELECTRICAL MEASUREMENTS

In the preceding chapter the connections of the various instruments have been shown. The various electrical units, such as amperes, volts, frequency, etc., are easy to measure in practically all cases, since the quantities are read direct on the proper instrument. It is a simple matter to measure the volts and amperes of a direct current circuit and thus obtain the power, but measurements in polyphase systems are not quite as easy.

Direct Current Power

In Figure 93 is shown the proper method of obtaining the input of power to a direct current motor. This same connection is used for obtaining the watts or power in any direct current circuit. (Watts = amps. × volts.)

Single-Phase Power

The power in a single-phase system may be measured directly by means of a wattmeter, as already shown in Figures 84, 85 and 86. Any Weston wattmeter will read the watts directly and accurately regardless of frequency, power factor, or wave form on any commercial current. It may also be determined by multiplying the volts by the amps. and the power factor of the system. (Watts = volts × amps. × P. F.)

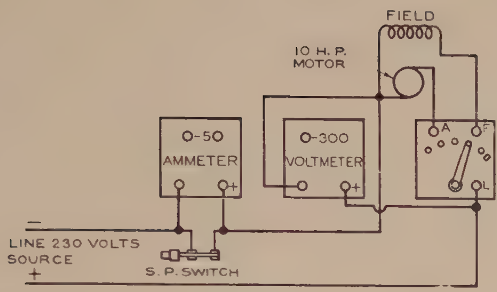


Fig. 93. Diagram of Connections for Load Test of Direct Current Motors

Two-Phase Power

In a two-phase, four-wire system, two single-phase wattmeters or a polyphase wattmeter are required. If two single phase wattmeters are used, each phase is measured separately and may be considered as two independent single phase systems. The total watts equals the sum of the two readings. (See Figure 87.) If both phases are balanced one wattmeter may be used and its reading doubled.

For three-wire, two-phase systems the method and connections are the same as given for three-phase, three-wire systems. (See Figures 87 and 90.)

Three-Phase Power

The most convenient method for measuring power in a three-phase, three-wire circuit is by means of the well known two-wattmeter method. For this measurement either a polyphase wattmeter may be used or two single-phase wattmeters as shown in Figure 87. A polyphase wattmeter consists of two single-phase wattmeter elements connected to a common staff and pointer. For this reason it can be used on either single or polyphase circuits. The total watts indicated by this instrument gives directly the algebraic sum of the two readings. The readings are correct for either a balanced or unbalanced system at any power factor.

When using two single-phase wattmeters as shown in the diagram the total power expended in a three-phase, three-wire system is the algebraic sum of these wattmeter readings. Care should be taken to have the instruments connected correctly with regard to their polarities. The polarities shown in diagrams should be followed in order that the proper relation exist between the currents in the current and potential coils of the wattmeters. When the

power factor of the system is above 50%, both wattmeter readings will be in a positive direction and the total power will be their sum. One of these readings will be larger than the other except at unity power factor for a balanced system, where both readings will be positive and equal. When the power factor of the system is below 50% one of the wattmeters will indicate in the reverse direction (negative) and in order to get its reading its current circuit must be reversed. The total power in this case will be the difference of the two readings; the larger reading is always positive. At a power factor of 50% one wattmeter will indicate zero.

How to Measure Power Factor

Power factor is the ratio of the true watts to the apparent watts. If one is not using a power factor meter, it is necessary to obtain the true watts with a wattmeter and the apparent watts by means of the ammeter and voltmeter, all instruments being connected in the same circuit. In Figure 94 is shown connections for measuring power factor in a two or three-phase, three-wire circuit. By adding current and potential transformers in the wattmeter circuit, the power factor of any balanced high voltage system may also be determined.

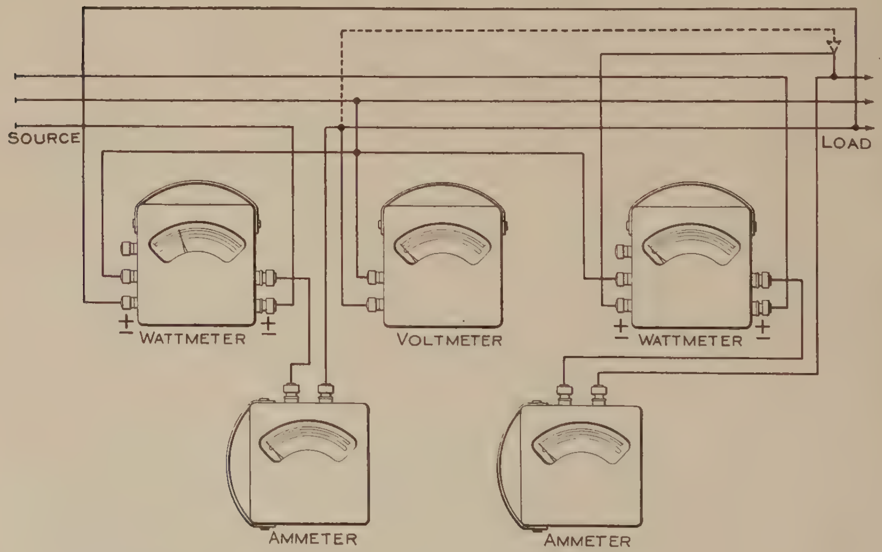


Fig. 94. Method of Measuring Power Factor on Polyphase Circuit

The watts obtained by the wattmeter should be divided by the volt-amperes as obtained on these respective instruments.

The power factor of a single-phase A. C. circuit $= \frac{\text{True Watts}}{\text{Apparent Watts}} = \frac{\text{Wattmeter readings}}{\text{Amperes} \times \text{Volts}}$

Balanced load three-phase power factor $=$

$$\frac{\text{True Watts}}{\text{Apparent Watts}} = \frac{\text{Wattmeter Readings}}{\text{Amps} \times \text{Volts} \times 1.732}$$

In two and three-phase circuits the power factor will be the same in all phases provided the lines are balanced; if, however, the lines are not balanced, each phase will have a different power factor.

In a balanced three-phase circuit the power factor may be obtained from the readings of two single-phase wattmeters or by the use of a single polyphase wattmeter. First take power readings in the circuit, being sure that the instruments, or instrument circuits, are properly connected with respect to polarity, as stated under the measurement of three-phase power, Page 101. The method of determining power factor from the wattmeter readings is as follows:

If $\Phi =$ the phase angle of the system

$W_1 =$ the larger of the two wattmeter readings

$W_2 =$ the smaller of the two wattmeter readings (with its sign)

$$\text{tangent } \Phi = 1.732 \times \left(\frac{W_1 - W_2}{W_1 + W_2} \right)$$

From a mathematical table of cosines and tangents the cosine Φ corresponding to this tangent Φ found above may be obtained, which is the power factor of the system.

This method of computing the phase angle or power factor requires that the system be balanced.

To use the Model 329 polyphase wattmeter for measuring this power factor, the instrument is to be connected as shown in Figure 90, care being taken that the polarities of the circuits are correct. The potential circuit of one phase is opened by removing the wire connected to its binding posts and a reading is taken; the wire then replaced and the second wire leading to the other potential circuit is removed and a second reading taken. These readings may be substituted in the formula given above or a more convenient method may be followed by using the following curve, Figure 95, which gives the relation of the power factor to the ratio of the wattmeter readings:

$$\text{Ratio} = \frac{W_2}{W_1}$$

where $W_2 =$ smaller reading and $W_1 =$ larger reading. With the ratio of the smaller (with its proper sign), to the larger reading, the corresponding value of power factor may be found from this curve.

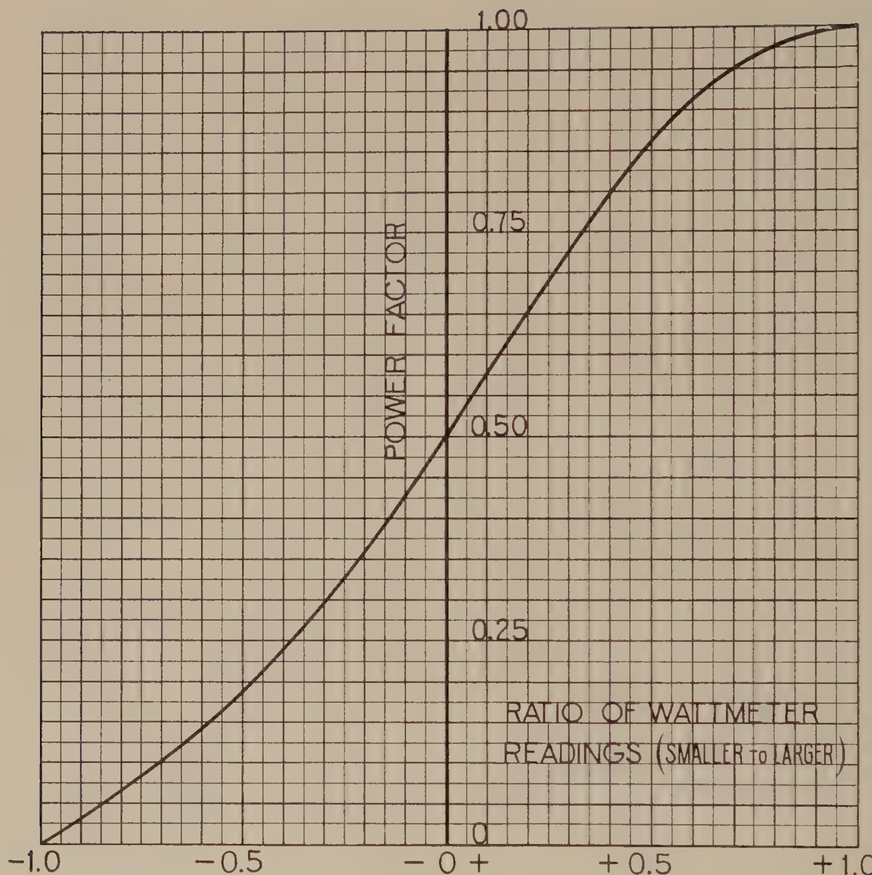


Fig. 95. Ratio of Wattmeter Readings (Smaller to Larger)

Examples

Suppose wattmeter reading $W_1 = 10.00$ K. W.
Suppose wattmeter reading $W_2 = 6.50$ K. W.

$$\text{Ratio of wattmeter readings} = \frac{6.50}{10.00} = 0.65$$

Power Factor
From formula, Page 103, cosine $\Phi = 0.939$
From curve, Figure 95, cosine $\Phi = 0.937$

Also suppose wattmeter reading $W_1 = 8.00$ K. W.
And suppose wattmeter reading $W_2 = —2.00$ K. W. (read by reversing current terminals)

$$\text{Ratio of wattmeter readings} = \frac{—2.00}{8.00} = —0.25$$

Power Factor
From formula, Page 103, cosine $\Phi = 0.327$
From curve, Figure 95, cosine $\Phi = 0.325$

In the above formula and table a sine wave is assumed.

Resistance

There are several methods of measuring resistance and the best method to use will depend entirely upon circumstances. In some cases a Wheatstone bridge is best adapted, but for all general work either the "Drop-of-Potential" method or an ohmmeter, as illustrated in Figure 31, will be found adequate. The average of several readings, using different currents, should be taken for the resistance, when using this method. The "Drop-of-Potential" method is based on Ohms Law, $R = \frac{E}{I}$, and is the most common one in use. This method, of course, requires some calculations and where these are undesirable and extremely rapid work is desired, the use of an ohmmeter is recommended. For extremely high resistances the use of an ordinary voltmeter will answer the bulk of the requirements. (See following paragraph.)

Insulation Resistance

The insulation resistance of electrical machinery may be measured by means of a direct current Weston voltmeter having a high resistance. A source of direct current, preferably of high voltage, is necessary and the connections are made as shown in Figure 96, from which it will be seen that the voltage of the battery or generator is first obtained and then a second reading of the voltmeter is made when the battery or generator is connected in series with the voltmeter and apparatus under test. The resistance is obtained as follows:

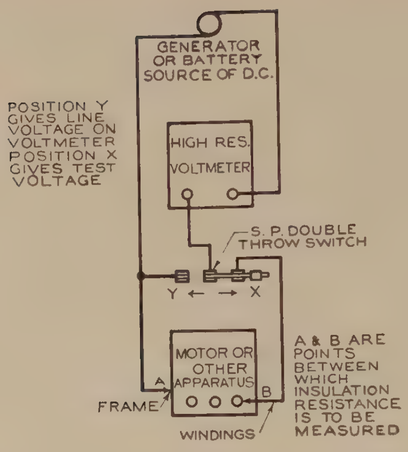


Fig. 96. Connections Used in Obtaining the Insulation Resistance of Electrical Machinery

$$\text{Insulation Resistance} = \text{Voltmeter Resistance} \times \left(\frac{\text{Line Voltage}}{\text{Test Voltage}} - 1 \right)$$

For example, the insulation test of a motor gave the following readings: Line voltage 220 (position "Y" of switch), second reading with voltmeter in series with motor 4 (position "X" of switch). Resistance of Weston voltmeter 30,000 ohms. Using the above formula the insulation resistance is as follows:

$$\text{Insulation Resistance} = 30{,}000 \times \left(\frac{220}{4} - 1 \right) =$$

$$30{,}000 \times (55 - 1) = 30{,}000 \times 54 = 1{,}620{,}000.$$

Insulation Resistance = 1,620,000 ohms or 1.62 megohms.

Capacity

The measurements of small capacities until recent years was extremely difficult, and at its best a laboratory method. There has been a large demand for an accurate, portable meter that would measure capacity direct, and for this reason the Weston Model 372 Microfaradmeter has been furnished. This instrument is shown in Figure 97 and can be furnished in ranges from .001 to 10 microfarads. The quantities read direct on this instrument and no calculations are necessary.

Fig. 97. Model 372 Capacity Meter

Impedance

Impedance may be found by means of "Ohms Law" for alternating current circuits, which is $Z = \frac{E}{I}$. In this case impedance consists of two quantities, reactance and resistance. Either one may be determined by eliminating the other. The formula for impedance is $Z = \sqrt{X^2 + R^2}$. From this formula it will be seen that by determining the impedance of a circuit and then measuring its resistance the reactance may be obtained. For example, consider a circuit having 3 ohms of resistance and 4 ohms of reactance. The impedance of such a circuit would be 5 ohms.

$$Z = \sqrt{3^2 + 4^2} = \sqrt{9 + 16} = \sqrt{25} \text{ or } Z = 5 \text{ ohms.}$$

From the above it will be seen that the impedance of the circuit may be obtained by the use of ordinary indicating instruments. With this method it is necessary to consider the current taken by the voltmeter and the impedance of the ammeter, although these may often be neglected.

Reactance

The simple formula for reactance is $X = 2\pi f L$. The only difficult thing to obtain in this equation is the inductance of the circuit L. As reactance is expressed in ohms, its value may be determined directly by the ammeter and voltmeter provided the resistance of the circuit is relatively small. If the resistance can not be neglected, then the reactance can be determined by determining the impedance of the circuit and working backwards. The reactance of a circuit $X = \sqrt{Z^2 - R^2}$. If the reactance has been determined, the value of the inductance may be calculated provided the frequency of the test circuit is accurately known, as shown in the original formula. Transposing for inductance $L = \frac{X}{2\pi F}$.

Chapter XI

INSTRUMENT STANDARDIZATION

As the subject of instrument standardization is so well covered in modern text books, we will not attempt to repeat it here, but will consider it in connection with the facilities already mentioned in the chapter entitled "Designing and Equipping a Laboratory."

All instruments should be kept in perfect condition at all times and this will be much easier and less expensive if high-grade instruments are used. It is the duty of any laboratory to keep its equipment in perfect order and the moral effect on the public, the Utility Commission and the employees will be a great asset. A laboratory is often judged by the instruments it has and their accuracy. A good engineer has no confidence in a poor or inaccurate instrument.

It is difficult to lay down any fixed rules as to when checking is necessary, as this depends upon the condition of the instruments and how much they are in use. However, some system should be in force for the checking of all instruments periodically.

When instruments are in continued use, the schedule on page 109 is suggested as representing good practice.

This table (Figure 98) is taken from Page 335 of the Handbook for Electrical Metermen, Fourth Edition of 1923, and is used by practically all the large companies in the country.

For the small laboratories having only a few instruments, arrangements should be made with a laboratory of a large utility, the manufacturers of the instruments, or some scientific university, for their standardizing.

The Weston Electrical Instrument Corp. maintains a very extensive standardizing laboratory and is prepared to calibrate or check instruments of their own make at any time. In Figure 99 is shown a chart illustrating the checking relations of the various instruments from a standardizing standpoint. The fundamental point in instrument checking is to have the standard meter read accurately and have a greater accuracy than the meter under test. From this chart it will be seen that switchboard instruments may be checked direct from the regular run of Weston portable instruments. This is due to the fact that switchboard instruments are not as accurate as portable instruments. If, however, switchboard instruments are checked in standardizing laboratories and secondary standards are available ready for use, much time will be saved in checking and calibrating.

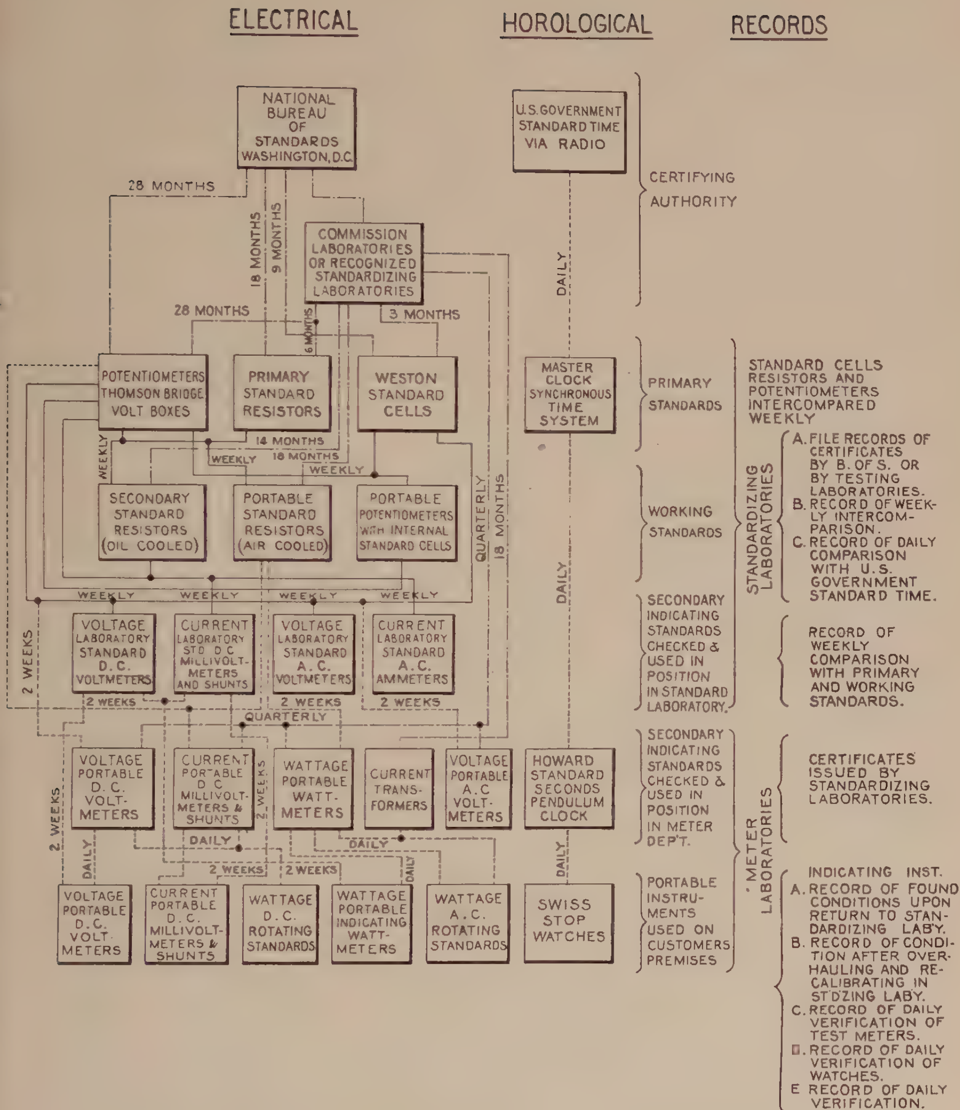


Fig. 98. Schedule for the Standardization of Instruments Used in Meter Testing

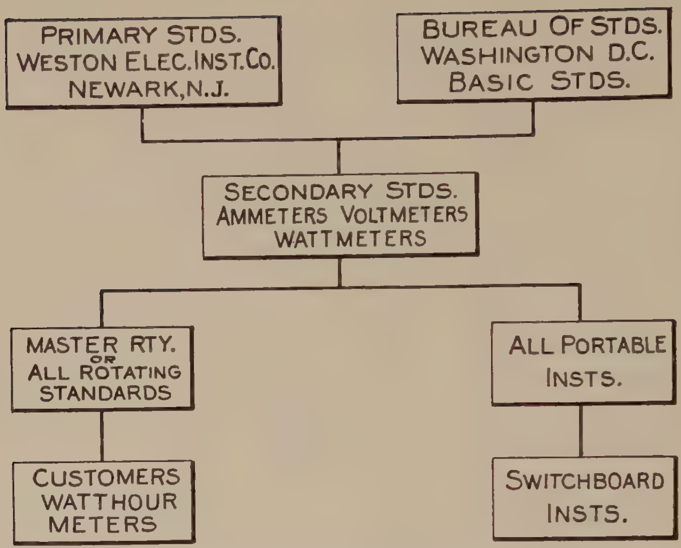


Fig. 99. Checking Chart of Electrical Measuring Instruments

When acceptance tests are made on equipment, all instruments used should be checked before and after the test.

The calibration or checking of instruments requires great care and the accuracy of the work will depend upon the facilities available and the ability of the engineer to read instruments. To be able to read measuring instruments accurately and quickly requires practice and a thorough understanding as to the exact value of each scale division. When a pointer stands between two divisions, it requires good judgment to be able to accurately estimate the fraction involved.

The scale provided on a Weston Laboratory Standard Instrument is divided in such a way that fractional parts are easily read. This scale is shown in Figure 100. The vertical line represents the large units of the value of the quantity being measured. The fractions are taken care of by means of the horizontal and slanting lines.

If possible, instruments should be carried by hand after being sent away for checking, but if this is not possible, they should be carefully packed, preferably with excelsior, first wrapping the instrument with paper.

Direct Current Voltmeters

Direct current voltmeters are checked by comparison with a standard instrument of known accuracy. When the facilities shown in Figure 17 are

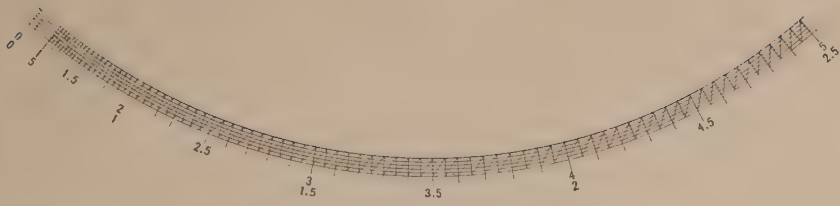


Fig. 100. Scale of Laboratory Standard Instrument

used for checking voltmeters, the instrument to be checked is connected to the test binding posts and the flexible connection "E" is placed under the binding post corresponding to the proper voltage. For example, a 150-volt instrument would be connected to the test terminals and if this meter is of the Weston permanent magnet type, the pole changing switch would be put in proper position for giving correct polarity. The flexible connection "E" is then placed under the binding post marked "150." Voltmeter switch "A" is then placed on the 150-volt connection and voltmeter switch "B" turned so as to connect the 150-volt coil of the standard meter in circuit. Checks may then be made by turning on the main switch and regulating rheostats "R160" and "A" and "B." By using facilities referred to above, a check of any voltmeter is a very simple matter and the work can be done at a rapid rate. If the voltmeter to be checked is of the electro-dynamometer type and reversed readings are desired, the polarity can be changed by means of the reversing switch shown in the diagram.

Direct Current Ammeters

The calibration or checking of direct current ammeters requires a steady current, preferably from a storage battery. The arrangement already shown in Figure 23, Page 35, will check ammeters of any range up to 2,000 amperes.

Either the self-contained instrument or its external shunt is clamped to the adjustable lugs and the leads of the standard instrument connected to the standard shunt being used. The proper rheostat is then regulated for obtaining the proper readings.

If an ammeter reading 0 to 1,000 were to be checked, its shunt would be connected to the lugs shown at the right of Figure 23. Its leads would then be connected to the shunt and the leads of the standard instrument connected to the 2,000 amps, precision shunt. The main switch would be turned "on" and rheostat "I" adjusted for the proper readings.

For instruments reading 200 amps or less, the lugs shown at the top of the Figure are used and the standard instrument leads connected to the proper shunt for the particular range. A 20-amp. instrument would use the 20-amp. shunt and rheostat 3 for regulating.

Millivoltmeters

The millivoltmeter is calibrated and checked exactly the same as the regular voltmeter, as already illustrated in Figure 24, Page 38. These facilities should be made a part of the work done on the direct current ammeter table, shown in Figure 23, Page 35.

Milliammeters

These instruments are checked by comparison with a laboratory standard voltmeter, as shown in Figure 101. Standard resistances are connected in series with the milliammeter and preferable of such a value that the instrument resistance may be negligible in comparison and the values of current obtained from Ohms Law. In Figure 101, assume that the voltage shown on the standard instruments was 100 and that the resistance in series with the milliammeter was 1,000 ohms, the instrument resistance being about 0.5 ohms—then the actual current flowing in the milliammeter circuit would be .1 ampere, $I = \frac{E}{R} = \frac{100}{1000} = .1$. If the instrument resistance is not negligible it must be added to the series resistance.

It is suggested that these facilities be available for use on the table set up for checking direct current voltmeters, Figure 17. This simply means the addition of some standardizing resistances, with values depending entirely upon the ranges of the milliammeters to be checked.

Alternating Current Voltmeters

The checking of alternating current voltmeters is exactly the same as that described for direct current voltmeters. Proper facilities were described on Page 34 and shown in Figure 22. Voltmeters of the induction type should be checked on a circuit of the same frequency and wave form as that on which they are to be used.

Alternating Current Ammeters

Alternating current ammeters are calibrated or checked by reference to some standard, in many cases a direct current being used. By using the facilities already shown in Figure 25, alternating current ammeters of any size up to 2,400 amperes may be easily and accurately checked. The method

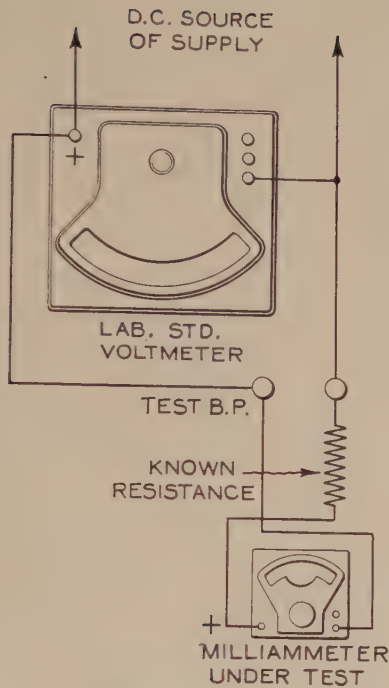


Fig. 101. Method of Checking Milliammeters

of checking ammeters having a range of not over 5 amperes is as follows: The ammeter is connected to the binding post marked "Small ammeter 0-5." The control switch for short circuiting either the wattmeter or ammeter should be placed in its left-hand position, cutting out the wattmeter. The switch controlling the 40-20-10 current transformer at the extreme right should be closed and the swivel switch connecting its secondary in circuit should be placed in its extreme right-hand position. The short-circuiting switch on this particular transformer should then be open and all other switches turned off. The plugs on the terminal board of this transformer should be in their proper position as directed in the cover of the transformer. By following the connections, it will be seen that the standard ammeter and that being checked are connected in series with the current transformer supplying the current for checking. The actual check is then made by turning "on" the "current" or "main" switch and regulating the value of current by means of the regulator. Ammeters having a greater range than 5 amperes should be connected to the binding post marked "Large Ammeter." By means of the transformer switches and swivel switch, the standard ammeter is connected into circuit containing the proper transformers.

If an ammeter reading 0 to 500 is to be checked, the following method should be followed: The 1,000-ampere switch connecting the 1,200-ampere current transformer should be placed in its upward position. This gives a ratio of 600 amperes to 5. The swivel switch should then be placed in its second position from the left, which connects the secondary of the current transformer to the standard ammeter. The wattmeter is cut out of circuit. All other switches are "off." The ammeter is then ready for checking, great care being taken to use the proper multiplying value on the standard ammeter, which in this case with a 5-ampere scale would make each ampere division have a value of 120. If this particular ammeter under test was supplied with a current transformer, the transformer itself would be connected to the same binding posts also marked "current transformer." In this case the ammeter, which would probably read 0 to 5, would be connected to the binding post marked "Meter under Test." The method of checking would be the same.

Indicating Wattmeters

When checking wattmeters the potential or voltage is maintained at its normal value and the current varied so as to reproduce actual working conditions of the meter. Facilities already described for checking alternating current ammeters are suitable for checking wattmeters, either with or without their current transformers. The current coil of the wattmeter is treated exactly the same as an ammeter and taps are provided in the potential circuit for connecting the potential coils of the instrument. By means of a phase shifter, various power factors may be obtained. Great care must be exercised to use the proper multiplying values when checking meters.

Polyphase wattmeters are checked with their current coils in series and their potential circuits in multiple.

Rotating Standards and Watt-hour Meters

Direct current rotating standards may be checked with the same facilities already described for wattmeters, and shown in Figures 17 & 23, Pages 27 & 35. Alternating current rotating standards are easily checked when using the facilities already shown in Figure 25, Page 39. The addition of some accurate timing device must be used in connection with the facilities shown.

Shunts

Switchboard shunts may be checked by means of a standard ammeter and millivoltmeter. Known currents of the proper values should be passed through the shunt and its voltage "drop" noted. These shunts are ordinarily adjusted

to have a "drop" of 50 millivolts, or for special purposes 100 millivolts, when passing their maximum rated current. The value of the "drop" is stamped on each shunt. This work may be easily accomplished where direct current standards are available. See Figure 23, Page 35.

Frequency Meters

Frequency meters can be checked when the exact speed and number of poles of the generator are known.

The simplest method for checking frequency meters is by means of a revolution counter and stop watch.

This method can be made to give high accuracy if care is taken in starting and stopping the revolution counter relative to the stop watch readings, and if the duration of the test is sufficiently long.

The frequency is then computed by the following formula:

$$\text{Frequency in cycles per second} = \frac{\text{No. of Poles} \times \text{R.P.M.}}{120}$$

Power Factor Meters

Power factor meters are quite difficult to properly check, although they may be checked with laboratory standard ammeter, voltmeter and wattmeter, provided some means is available for varying the power factor of the circuit. We strongly recommend these instruments to be sent to the manufacturer or to the Bureau of Standards for check.

Ampere-hour Meters

Ampere-hour meters may be checked by using the same facilities as outlined for direct current ammeters with the addition of some accurate timing device.

Current Transformers

The ratios of current transformers may be compared by using the facilities already shown in Figure 25, Page 39. The second ammeter, by which the comparison is made with the standard ammeter, must be properly checked before the test on the transformer itself can be made. In this test the readings of the ammeter are compared, from which the ratio of the transformers is determined.

Potential Transformers

Ratio Test

Potential transformers are checked by reference to a Standard transformer of known accuracy by using a Weston Comparator Voltmeter, shown

in Figure 29, Page 47. The connections for using this instrument are also shown in Figure 28, Page 46, and the method of checking will be described.

It is advisable to connect the movable and field coil circuits together, as shown, to eliminate any possible electro-static attraction between these circuits.

When connected as shown in Figure 28, the instrument indicates the difference in voltage of the secondaries of the two transformers and from this reading and the known ratio of the standard transformer, the ratio of the transformer to be measured can be determined.

If it is desired to test the transformer for any particular secondary burden the burden should be connected across the terminals "tt."

It is always advisable to first connect the 250-volt range to the two transformers which are supposedly in opposition so that if an error has been made in connections, or one has reversed polarity the instrument will not be damaged. If the voltage to be measured is found to be sufficiently low then a lower range may be used. The object of the spring switch "D" is to always keep the 250-volt coil in circuit when low readings are not being made. In this test switches "B" and "C" should be placed in the opposite direction from that shown in the diagram. The high voltage side of all transformers should be connected together through B. P. "F."

The plug for the plug switch in the field circuit should be placed in the hole which corresponds most closely to the voltage across the field circuit. This can always be adjusted to within 2.5 volts of the correct value or within about 2.5%.

Assuming the test and standard transformers differ by one volt, then the error involved due to the coarseness of the resistance steps in the field circuit would be 2.5% of 1 volt or 0.025 volt or about 0.023% for a transformer having a 110-volt secondary.

From this it is seen that for ordinary work it will answer all practical requirements to merely put this plug in the hole most nearly corresponding with the voltage applied to the field circuit. For the highest precision, however, the voltage of the supply should be regulated to one of the even values for which the field circuit may be exactly adjusted.

If a voltmeter is at hand, it will be more convenient to use it for measuring the voltage across the field circuit, as shown. If no other voltmeter is available, the instrument itself may be used as a voltmeter by connecting the field and movable coil circuits in multiple to the same source of voltage and adjusting the plug switch until the plug stands in the hole corresponding to the voltage indicated on the scale.

If this operation is performed using the field circuit supply transformer as a source of voltage then the voltages of either the standard or test transformers

may be determined by shifting the leads of the movable coil circuit to the terminals of these transformers.

Having determined the difference in voltage between the standard and test transformers, as well as the secondary voltage of the standard transformer, the ratio of the test transformer may be determined as follows:

Let V = the secondary voltage of the standard transformer.

Let v = the difference in voltage of the standard and test transformers.

Let R = the ratio of the standard transformer and R_1 the ratio of the test transformer. Then $R_1 = \frac{VR}{V + v}$.

In this formula v should be treated as + when the pointer deflection is to the right and as — when the pointer deflection is to the left.

For example, suppose V is 110 volts, R is 19.95 and the pointer indicates 0.85 volt low, i.e. deflects to left. Then $v = -0.85$ and

$$R_1 = \frac{110 \times 19.95}{110 - 0.85} = \frac{110 \times 19.95}{109.15} = 20.10 +$$

Phase Angle Test

To measure the phase angle of the test transformer, connect to a two-phase or three-phase circuit as shown. If only three-phase current is available, it may be transformed to two-phase by any of the well known methods of transforming from three-phase to two-phase currents or the measurement may be made directly on three-phase current as directed later.

As in the ratio measurement, the plug should be placed in that hole in the plug switch which corresponds to the voltage across the field circuit. The voltage indicated on the scale in this case is the difference in the quaderature components of the secondary voltages of the standard and the test transformers.

If V = the secondary voltage of the standard transformer and v the indication on the scale, then the sine of the difference of the phase angles of the two transformers $= \frac{v}{V}$.

The magnitude of the difference in phase angles of the two transformers in minutes may conveniently be determined by dividing the sine of the angle by 0.000291. This method is very accurate for angles not exceeding a few degrees.

Measurement of Phase Angles in Potential Transformers Using a Three-Phase Current Source

When three-phase current only is available and it is not convenient to transform this to two-phase current, the phase angle may be measured on three-phase current by following the directions given below.

In making this test with three-phase currents, switch "C" is left in its downward position, as shown, and switch "B" is used in both positions.

The algebraic sum of the readings taken by using switch "B" in both positions is the sine of the difference in phase angles of the two transformers and corresponds to the single reading in the case of the use of the two-phase circuit described above.

The methods for determining whether the angles are lagging or leading are given in detail in the instructions accompanying the instrument.

Measurement of Phase Difference in Circuits

In many cases it is necessary to know the phase angle or angular difference in phase between the currents in the elements of relays and between these currents and the currents in, or the potential across, any other circuits where these relations are desired to be known. For such measurements the Weston Model 480 Phase Angle Meter has been developed.

The instrument operates upon the electrodynamometer principle and has two circuits which are insulated from each other. One circuit, called the potential circuit, is designed for direct connection to 110 volts, 55 volts or 15 volts, as desired. The instrument, therefore, actually indicates the phase angle in degrees between the current in the field circuit and the voltage across the potential circuit.

The phase angle instrument differs from the power factor meter inasmuch as it measures the angular difference instead of the cosine of the angle between currents or potentials or both. The scale of the power factor meter does not go below .5, but the phase angle instrument has a scale reading from zero to 90°.

A switch is provided by means of which the scale may be read for current angles in any of the four quadrants.

A second switch is provided by means of which the instrument may be used on circuits of either 25 or 60 cycle frequency.

The resistance and inductance of the current circuit have been reduced to such low values that its insertion into any of the relay circuits will not appreciably change the currents in those circuits or their phase relations.

The accuracy of the instrument will be within 1° for currents in its current circuit as low as 1 ampere, and the accuracy will not be seriously impaired for currents down to ½ ampere.

The instrument is used as follows:

The potential circuit is connected across the local voltage supply circuit which is considered the standard or zero phase. Then to determine the phase

of the current in any circuit it is only necessary to insert the current or field circuit of the instrument in series with the circuit to be tested. When connected in this way, the meter will read the difference in phase angle between the current and potential circuit. See diagram of connections shown in Figure 102.

Suppose it is desired to measure the phase angle between two currents, I_1 and I_2 in a relay having two current circuits, considering that the positive directions of the current must be known relative to the relay or any phase angle measurement would, of course, be meaningless.

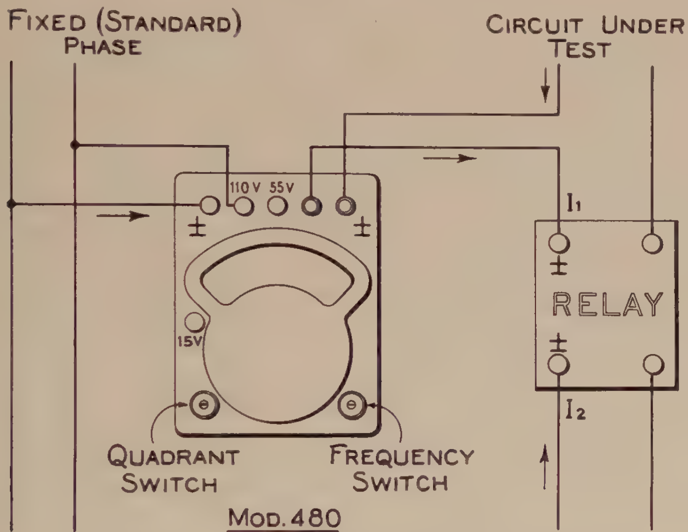


Fig. 102. Connections for Model 480 Phase Angle Meter

Connect the current circuit of one of the elements to the phase angle meter so that the current binding posts have the correct polarity as assumed for the positive direction of the current. Also connect the potential binding posts and set the frequency changing switch to the frequency of the circuit under test.

Turn the quadrant switch on the left hand side of meter until a deflection is obtained on the scale. The current considered as a vector is then in that quadrant marked on the switch and differs in phase from the vector V+ or V— by the amount indicated on the scale. V+ in Figure 103 is considered the standard voltage vector.

Let us assume that a deflection on the scale is obtained with the switch in position marked $+V_1$ and the meter indicates 28°, which we will call Φ_1, Figure 103.

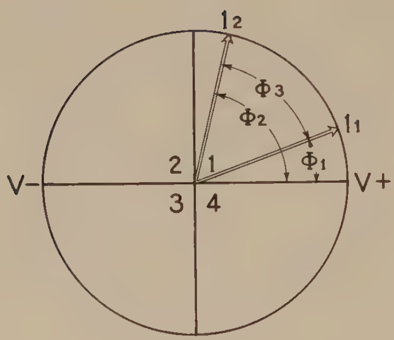


Fig. 103.

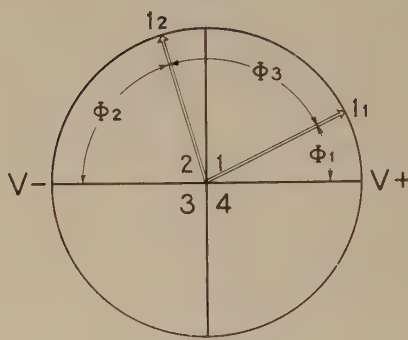


Fig. 104

Now to determine the phase relations of the current I_2 in the circuit of the relay the local circuit connections must be removed from the instrument and the other or second circuit connections substituted, with the same regard to polarity as previously described. The connections to the voltage circuit should be left unchanged, for this gives the positive direction $V+$ in the diagram. Again turn the switch until a deflection on the scale is obtained.

Assume the angle Φ_2 to be 80° as shown in Figure 103, and the switch at $+V_1$.

The phase angle between I_1 and I_2 is then $\Phi_3 = (\Phi_2 - \Phi_1) = 80° - 28° = 52°$.

Again, referring to Figure 104, let us suppose it was necessary to turn the switch to position $-V_2$ to obtain a deflection on the scale when the second current circuit was connected. Also assume the deflection to be 70°. This shows that the current vector is in quadrant 2 and 70° from vector $V-$. The angle between the currents Φ_2 and Φ_1 is then $180° - (\Phi_1 + \Phi_2) = 180° - (70° + 28°) = 180° - 98° = 82°$.

In general the method is first to determine upon a positive direction of the voltage circuit, by obtaining a readable deflection for one of the currents under test and then operate on the other currents to be tested, noting whether the angle is measured from $V+$ or $V-$.

In taking notes in the field it is simply necessary to record the angle and the quadrant in which it is located as given by the positive of the switch, for example: First Circuit Current $= (+V_1)$ 28° Second Circuit Current $= (-V_2)$ 70°.

Chapter XII

EXPLANATION OF A FEW ELECTRICAL TERMS

As most electrical terms are familiar to the laboratory engineer, it is not our intention to review them all in this Instruction Book. There are a few in use, however, which are not generally understood and therefore we explain them briefly.

Power Factor

We are mentioning power factor and are treating it in an elementary way so that those engineers who come in contact with industrial plants can best explain the matter to this class of customers. Furthermore, we are considering the customer's load from a power factor standpoint, as it is this load that determines the power factor of the central station system. Practically all central stations appreciate the necessity of educating the customer as to the beneficial results to both parties when power factor is at its highest.

It is a term hard for the layman to understand and difficult for the engineer to explain.

Power factor is always present in an alternating current plant. When the power factor of an alternating current circuit is 100% or unity, we have then reached the best operating condition so far as power factor is concerned. Low power factor is detrimental and when it reaches a value as low as 50% it becomes serious in most cases. A system having a power factor of 90% is considered good and today there are few systems as a whole operating at much above this figure, except perhaps for lighting purposes only.

Power factor may be considered in the following manner: The current supplied to alternating current apparatus may be considered as consisting of two parts, one which performs useful work in driving motors, etc., while the other performs the unuseful but necessary work of creating magnetic or electric fields or both. This second current is consumed in energizing the magnetic fields of the motors and other magnetic apparatus. In the case of direct current apparatus, the energy to supply the magnetic fields is furnished by the line once and for all when the circuit is first closed. The line then merely supplies the relatively small current necessary to maintain the field constant.

In the case of alternating current apparatus, however, the magnetic fields are magnetized in one direction, then demagnetized; then magnetized in the opposite direction and again demagnetized during each cycle, or sixty times in a second for a 60-cycle frequency. This comparatively large amount of energy is supplied by the power house during one portion of the cycle, then

returned to the power house during another portion of the cycle, which causes a continuous surge of energy or current, back and forth over the line, which results in no net or useful work, as this energy is simply borrowed and returned during each cycle.

The first or useful current multiplied by the voltage equals the true watts, while the second or unusable current multiplied by the voltage equals the so-called reactive power which performs no useful work.

The higher the power factor, the lower the value of the second or unuseful current. To further illustrate, consider the actual measurements taken on a single-phase circuit supplying current to an induction motor. Measurements are taken by means of an ammeter, voltmeter and wattmeter. When under test the voltmeter reading is 220 volts, the ammeter 20 amperes and the wattmeter 3,520 watts. If we multiply the amperes and volts together to obtain the watts the same as we do in direct current, their total would be 4,400, which would be the apparent watts.

The wattmeter, however, indicates 3,520, which is the true watts actually taken by the motor because it only indicates the useful power. The ratio between these two figures equals the power factor, that is, 3,520 divided by 4,400 equals 80%, or the power factor. The difference between these two figures, that is, 4,400 and 3,520, is 880 volt-amperes, which are an added burden to the generating and distributing systems without doing any useful work.

As previously stated, it is usually defined as the ratio of the true watts to the apparent watts. It is therefore necessary to obtain the true watts with a wattmeter, and the apparent watts by means of an ammeter and a voltmeter.

It is perhaps easier to thus consider power factor in its effect upon the current because it is the current that determines the size of wire and causes the heating, or stated in another way, it is the current supplying the energy surging back and forth to the power house to energize the magnetic fields that causes a loss in the line by a degree of heating depending upon the resistances of the line. Another disadvantage caused by low power factor is that generator equipment, transformers, transmission lines, etc., must have extra capacity in order to carry this extra current.

The reason that a wattmeter is so desirable for alternating power measurement is because it always measures the effective electrical power, whereas the voltmeter and ammeter method measures the vector sum of the useful and non-useful power which is of course very desirable to know because by comparing this with the wattmeter reading we can determine the power factor.

It should be borne in mind that it is possible to buy a power factor meter which will directly indicate the value of the power factor and when this value

is known, the total power as determined by the product of the voltmeter and ammeter readings may again be multiplied by the power factor to determine the useful or effective power.

From the above may be seen why central stations are interested in supplying loads having a high power factor. If the power factor is low it means that their entire system must be larger than is necessary in order to provide for this additional unusable current.

The Weston Electrical Instrument Corp. would be very glad to give to users of their instruments any possible assistance in their power factor problems, provided necessary information is furnished.

Load Factor

Another term which interests central station engineers is "Load Factor." By this is meant the ratio of the average to the maximum load of the entire plant for some particular time. In other words, it is the relation between the average load of a plant to its maximum load for say a day, week or a year. If the average load of a plant is one-half of its maximum load the load factor is then 50%. This item is of more importance to the isolated plant than the manufacturing plant purchasing outside power, as it directly affects the size and number of generating units.

Maximum Demand

A third term is "Maximum Demand" or peak load, by which is meant the largest amount of power used at any one time, say for a period of five minutes or over. This subject is of particular importance to the central station or isolated plant, as they must be equipped to carry this total load even if it only lasts a few minutes a day. For example: a plant might operate with a total load of 10,000 kilowatts for 23 hours a day but for the 24th hour its load would reach 20,000 kilowatts. The maximum demand of this station would be 20,000 kilowatts. It is, of course, desirable to keep the maximum demand as low as possible so as not to cause undue "peaks" on the power producing equipment, and to obviate the necessity of buying equipment of larger size or rating than the ordinary output warrants.

Regulation

The subject of "Regulation" is being mentioned especially for those engineers who come in contact with the industrial consumer. This subject is of extreme importance to the small utility not having generating and transmission facilities in sufficient sizes to carry the heavy loads and demands often imposed by certain classes of customers. From the following it will be seen that good regulation is especially desirable for lighting and that greater variations may exist for power installations.

It is impossible for any plant to maintain an absolutely constant voltage and, as a matter of fact, an absolutely constant voltage is not necessary for the average industrial plant. It should be, however, maintained within reasonable limits.

By "regulation" is meant the per cent of increase or decrease of the voltage from its normal predetermined value. If the standard voltage is 550 and it drops to 495 volts the regulation is then 10% below normal, as 10% of 550 equals 55, and 550 — 55 equals 495. A voltage of 583 would be 6% above normal as 6% of 550 equals 33 and 33 plus 550 equals 583.

"Regulation" is a serious problem for the central station, especially those of the smaller sizes. As a general rule, a variation of 10%, either above or below the nomal voltage, will have little effect on the operation of motors unless they are overloaded, but it will have an important effect on the lighting circuits.

In alternating current systems, it is especially important that the frequency of the circuit should be maintained within fairly close limits as the speed of alternating current induction and synchronous motors is directly affected by the frequency of the supply circuit.

"Regulation," in terms of speed, means the per cent of variation above or below the normal value of the motor rating under various loads when proper voltage and frequency are maintained constant.

In general, induction motors are affected by voltage variations as follows:

10% Above Normal

Increase speed about 1%.
Increased starting torque.
Efficiency is slightly better at full load.
Efficiency is decreased at less than full load.
Power factor is decreased.

10% Below Normal

Starting torque decreased nearly 20%.
Power factor slightly improved.

A voltage variation of more than 10% from normal is very undesirable and if below the normal motor rating it will cause excessive heating and a great reduction in its efficiency.

An increase in frequency means a higher speed and a slightly better power factor, but with decreased starting torque. A decrease of normal frequency reduces the speed and power factor but increases the starting torque.

The speed of direct current motors will vary with the supply voltage, increasing when above normal and decreasing when voltage is below normal. Its effect will be slightly different on the various windings found in direct current motors.

As the watts must be maintained to keep power output, low voltage in many cases means more current, because mathematically speaking, watts equal the products of voltage and current.

The question of proper voltage regulation is very important for incandescent lamps, as shown by the following table:

EFFECT OF VOLTAGE VARIATIONS ON TUNGSTEN FILAMENT (OR MAZDA) LAMPS

Volts Percent	Candlepower Percent	Total Watts Percent	Watts Per Candle Percent	Current Percent	Life Percent
95	83.1	92.2	111.0	97.0	216
96	86.3	93.7	108.7	97.6	185
97	89.6	95.3	106.3	98.2	158
98	93.0	96.9	104.2	98.9	136
99	96.4	98.4	102.0	99.4	117
100	100.0	100.0	100.0	100.0	100
101	103.6	101.6	98.0	100.6	86
102	107.4	103.2	96.1	101.2	74
103	111.2	104.8	94.2	101.8	64
104	115.1	106.4	92.5	102.3	56
105	119.0	108.0	90.8	102.8	49
110	140.3	116.3	82.9	105.7	25

Note: The left hand column represents the percentage of voltage from normal at the lamp terminals.

When the rated voltage of the lamp is 100% it gives its best service as will be seen by referring to the values in the above table. If the voltage is increased 10% or a total voltage of 110%, the candle power is increased 40.3%, but the life of the lamp is only 25% or ¼ what it would be with normal voltage. A reduction of 5 volts, or 95% of the rated voltage, reduces the candle power of the lamp to 83.1% but increases its life by 216%, in other words, it will last twice as long giving less light.

Chapter XIII

CONDUCTING TESTS IN THE FIELD

The testing of instruments in service outside of the laboratory is not always an easy matter but may be accomplished quite easily if only a portion of the scale of the instrument is to be checked. For example, it is not a difficult matter to use a high resistance slide wire rheostat when checking a switchboard voltmeter in service. Such a rheostat gives sufficient range to check the instrument near its working values. In such a case it is not necessary to check the entire

range of this instrument. By means of low voltage transformers or storage batteries, it is possible to check ammeters over a considerable range by disconnecting them from their regular circuit on the switchboard. The ease and rapidity with which this work may be accomplished will depend largely upon the accessory equipment used. By careful planning and with the use of proper accessory equipment a large amount of time can be saved. The first test is usually the hardest, as all tests made on a later date can be based upon the experience of the first.

It is strongly recommended that testing clips be placed on all instruments and meters that are frequently checked. The slight expense will save much time and reduce the hazard of coming in contact with live circuits.

Each company will have to work out its own problem of making checks in the field. It is a subject that will require careful study and one which should be thoroughly standardized.

In order that the best results may be obtained from the use of instruments in the field we offer the following suggestions:

Before making a test select some good location for the instruments, and provide a portable table (See Figure 48) or a large-size box placed as near the apparatus to be tested as possible but out of the way of operators in the station. Have all connections as short as possible and so made as to avoid crosses and contact with the apparatus. Be sure to keep all wires away from an aisle or thoroughfare and thus eliminate the possibility of accidents caused by wires becoming entangled with either individuals or machinery.

When the proper place has been provided for the instruments, see that they are level, or approximately level, and that the pointers rest on zero when all circuits are open. (This does not apply to frequency and power factor meters.) It would be well to make and check all connections on paper before the current is turned on and thus be certain that they are properly made. If possible, have a second party check the connections, as a mistake may cause the loss of an instrument or some apparatus, or result in injury to the individual making the test. Be sure the circuits are properly protected with fuses or circuit breakers, and that instrument circuits are not broken when tests are being made. Keep unshielded instruments away from stray magnetic fields produced by conductors carrying large currents, motors, generators, magnets, etc. If an unshielded instrument, such as a Model 1, is used in a stationary stray magnetic field it should be turned at an angle of 180° after the first reading and a second reading taken. The average of these two readings should be used.

We recommend the use of short-circuiting switches in connection with ammeters and current coils of wattmeters to protect them against heavy acci-

Fig. 105. Proper Method of Making Connections to Weston Model 310 Wattmeter When Small Wires Are Used

dental overloads. These switches should be of sufficient capacity to carry the entire current and should be "open" only when readings are to be taken. Be sure that you are short-circuiting the current coils and not the potential coils. The contact keys usually supplied on portable voltmeters will answer for a switch for these instruments. If the voltmeter is not provided with a contact key use a 5-ampere snap or small single pole knife switch.

Use nothing but insulated wire of the proper size in making the various connections (See Table 2, Page 145, and in order to avoid heating be sure that all contacts are clean and carefully made. In Figure 105 is shown a proper method of making connections with instruments when using small wire.

In cold or dry weather be very careful not to rub the glass covering the instrument dial as this will create "static" electricity on the glass and cause a false reading on the instrument. If the instrument is affected at any time by "static," it can be easily brought back to zero by breathing on the glass. Avoid the possibility of metallic chips and dirt falling between the contact blocks of multi-range current transformers. A contact between these blocks would "shunt" part of the current through the winding or windings and thus cause an error in the ratio.

Overhead light is desirable when reading instruments and the reader's eyes must be directly over the scale. A mirror is provided with the scale for determining the exact position of the pointer. When in the proper position, the pointer will be seen as a straight line directly over and hiding its reflected image in the mirror.

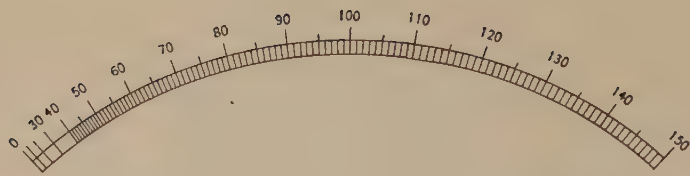


Fig. 106. Scale of Model 155 Voltmeter, 0-150 Volts

Be certain to understand the value of each scale division and if the instrument has more than one range, select the proper one before actual readings are taken.

Figure 106 shows the scale of a Model 155 Voltmeter reading 0 to 150. Starting at 40, the value of each division is 1 volt. Below 30 the first division is 20 and the lowest 10 volts. If you are using multiplier, current or potential transformer, be sure to use the correct multiplying factor.

All connections must be clean and tightly made, especially when heavy currents are used. Also be sure to securely fasten the connecting links on ammeters and wattmeters.

In making tests or calibrations in stations and sub-stations, two engineers or an engineer and an assistant will make more than proportionate progress

Fig. 107. Use of Key Tag for Instrument Identification

than when one man attempts the work alone. All connections in the plant having anything to do with the tests should be studied and thoroughly understood. Great care must be exercised in handling any live wires regardless of voltage. Do not handle live wires unless absolutely necessary and then only with extreme caution.

Chapter XIV

NUMBER SYSTEM FOR INSTRUMENTS, METERS AND TRANSFORMERS

When testing equipment consists of many instruments, it is a good policy to distinguish each by a special number instead of using the manufacturer's number upon the instrument. This suggestion may be adopted by a small key tag fastened to the instrument or by means of a small name-plate fastened to each instrument case. Some owners paint the details of the instrument on the outside case. These numbers can then be used for reference and quick identification. Figure 107 suggests a method of identification by using a common key tag. Never use nails to attach such tags or pound screws to start them.

Where instruments are kept in cabinets, the pigeonhole containing these instruments should be marked with the same number, making it easy to locate

Fig. 108. Laboratory Number Applied to Switchboard Instrument

quickly any particular instrument. Switchboard meters can best be marked by means of a small number pasted in some inconspicuous place or on the front of the meter, as shown in Figure 108. These numbers may be obtained from small calendars or may be purchased in gummed sheets from the Dennison Manufacturing Company of South Framingham, Mass.

In marking current and potential transformers, it is suggested that a number be placed on a small shipping tag. Numbers and tags should be covered with a transparent varnish or white shellac for protection. Where a large number of transformers are to be marked, these small tags, properly marked, may be purchased at a small cost. Such a system of numbering instruments, meters and transformers will be found of great convenience in making tests, as manufacturers' numbers are usually high and often difficult to read.

We also recommend a form of card to use in indexing instruments, as shown in Figure 109. On the back of this card may be recorded the checking record of the instrument.

Plants using many motors or generators should number each one for identification purposes. This may be done by painting a large red or white number on the machine where it will be easily visible. The corresponding switch or starting compensator should bear the same number. As the numbers on the name-plate are very hard to read and errors are likely to occur this is the best method of identifying apparatus. After painting the number, cover it with a coat of white shellac or light varnish to keep it clean. If data regarding each machine is on file, much time will be saved when tests, changes or repairs are necessary.

Chapter XV

SYSTEMATIZING, TESTING AND STANDARDIZING WORK

Laboratory engineers should devise some means for systematizing all the work of the department because if no definite plan of this sort is established there is constant danger of neglect of some important test—and it generally happens that the neglected tests are those which are most necessary.

In most medium-sized or small laboratories the necessity of periodic testing work has not been fully appreciated and our advice is that engineers in such plants make it a point to exchange ideas with those in charge of electrical laboratories of the large systems, where a definite testing routine is in practice because—generally speaking—these larger organizations are performing a work that is a great credit to the electrical industry.

(Name of Company)

Meter .... Current .... Shop No. ....

Make .... Maker's No. ....

Inventory No. .... Amps .... Volts ....

Value each scale division .... Phase ....

Date Purchased .... 192 .... From whom ....

Scales .... Leads .... Condition ....

Accuracy .... Weight .... Case ....

Model .... Potential Key ....

Reversing switch .... Multiplier ....

Shunts ....

(Checking record on back.)

Checking Record

Date 192			Date 192		
Std.	Meter No.	Correction	Std.	Meter No.	Correction

(Details of meter on other side.)

Fig. 109. Checking Card for Use With Instruments

Hence, we advocate that any laboratory, regardless of its size, should arrange a simple, but thorough, plan for periodically conducting tests and checks in the same careful manner that it arranges to audit its books.

Preferably this plan should include a card record of every instrument on which may be noted when it was last checked; its correction factor, if any; its guaranteed accuracy, etc. (See Figure 109.)

Likewise a record should be kept of each piece of machinery and apparatus so that one may quickly refer to its history as regards the last test; when inspected; what load it has carried; and when and why it was repaired, etc. This card might also show the connections made and the instruments and any calculations employed at the last test. Should these seem too much data to place on a card, the record can easily be kept in a large-size notebook. Such a notebook is shown in Figure 13, Page 24.

Proceeding on a definite business-like basis will serve to convince the management of the exact condition of the system at all times and will save much time and reduce expense.

It will also be of assistance to make and frame a complete diagram of the entire electrical system, showing the sizes and location of all apparatus, conductor, etc., and it will help if the management is given a duplicate copy, taking care that both copies are always up to date.

The better the employee understands the work carried on by the electrical laboratory, the easier it is to keep the system in good operating condition and thus prevent shut-downs and unnecessary expense.

A simple and carefully prepared method of systematizing checking is shown in the back of this book.

Companies having several hundred switchboard instruments and meters in their various generating and sub-stations will find these tabulation sheets of great assistance. While these sheets are practically self-explanatory, a few remarks about their use may be of assistance. The system requires each instrument or meter, together with its current or potential transformer, to be numbered as mentioned in the previous chapter. Current and potential transformers should have the same numbers as their respective instruments, using a letter after the number when more than one current or potential transformer is used.

After all instruments, meters, transformers, etc., have been numbered, a record should be placed on the forms referred to. In the last column on the right reference is made to "Check Sheet No." This sheet, shown in Figure 110, contains all the records and data of the checking of the instrument or meter and will be found very complete for field work.

(Name of Company)

Date................192

Order No. ....

Sheet No. ....

Tab. Sheet No. ....

METER ENGINEERS' CHECKING RECORD

Meter..................Lab. No...................Scale..................

Seal found..........left..........Tested with Current Trans. No..........

Zero found..........left..........Tested with Potential Trans. No..........

Hour of test..........M. Hrs. consumed in test..........Shunt..........

Adjustments ....

Meter tested at..

Name of Station ....

Station operator on duty..

LABORATORY METERS USED

Ammeters ....

Voltmeters ....

Wattmeters ....

Freq. ....

P. F. ....

Current Trans. ....

Potential Trans. ....

Shunts ....

RECORD OF TEST

INDICATING METERS

ACCURACY AS FOUND

Std. No.	Cust. No.	Error

ACCURACY AS LEFT

Std. No.	Cust. No.	Error

Lab. Am. No. Scale.......... Series / Parallel

Lab. Am. No. Scale.......... Series / Parallel

INTEGRATING METERS

ACCURACY AS FOUND

Rev. Std. No.	Rev. Std. No.	Rev. Cust.

Customer's Rev. =..........x..........=..........

Total Std. Rev. =..........x..........=..........

ACCURACY AS FOUND..........% Slow / Fast

ACCURACY AS LEFT

Rev. Std. No.	Rev. Std. No.	Rev. Cust.

Total Cust. Rev.=..........x..........=..........

ACCURACY AS LEFT..........% Slow / Fast

CIRCUIT DATA DURING TEST

Load KW.......... P.F..........

Amps. .... Volts..........

Load { Steady / Varying } Frequency..........

Load..........% Normal

RECORD of METER SCALES

Rty. Std. No..........Constant..........

Rty. Std. No..........Constant..........

Multiply by..........

Constant Cust. Meter..........

LAB. CURRENT TRANS.

Amps.......... Ratio..........

LAB. POTENTIAL TRANS.

Volts.......... Ratio..........

Lab. Wattmeter No..........Amps..........Volts..........Multiply by..........

Lab. Wattmeter No..........Amps..........Volts..........Multiply by..........

Test made by..........Checked by..........Approved by..........Sig..........

CHECKING TEST

Station current and potential trans. = % Slow / Fast

Lab. potential and station current trans.= % Slow / Fast

Lab. current and station pot. trans. = % Slow / Fast

Remarks: ....

....

(For convenient use enlarge to size $8\frac{1}{2}'' \times 11''$) (Over)

Fig. 110—Front Side

All blanks must be entirely filled out and one blank used for each meter tested.

Write plainly and keep sheets clean.

Check up all figures and calculations to avoid mistakes.

Make no repairs without a special order covering same.

The results of your work are the property of the Company and any employee may receive all data desired with the permission of the General Manager or his representative. Give no data to others.

If you notice any wrong connections, loose wires, excessive temperature, vibration or anything that effects the accuracy of a meter, mention it under "remarks."

In testing integrating meters, use the following formula:—

$$\text{Accuracy} = \frac{\text{Rev. Cust. Meter x Constant.}}{\text{Rev. Std. Meters x Constant x Trans. Ratios.}}$$

ABBREVIATIONS

Am.—Ammeter	Pot.—Potential
Cust.—Customer	Rev.—Revolutions
Hrs.—Hours	Rty.—Rotary
Lab.—Lab^ratory	Std.—Standards
P. F.—Powerfactor	Trans.—Transformers

Treat Every Wire As Bare and Be Careful in Handling Live Wires

(See other side)

Fig. 110—Rear Side

These forms are used as follows: Before the actual checks are made the station is visited and its metering equipment examined and numbered. After the numbering is completed, the tabulation sheets are filled out, giving details. On the reverse side of the sheet is listed the necessary instruments and facilities for making the actual checkings. When the actual checkings are made the form shown in Figure 110 is used and later the results are transferred to the large checking sheets. By means of such a system the work is greatly simplified and the possibility of error reduced to a minimum. One of its great advantages is to make the engineer conducting the test think carefully and to remind him of the data required.

Another form that will be found convenient for systems maintaining many generating and sub-stations is shown in Figure 111. This will assist the engineer in the field by giving him definite instructions about reaching the plant with his equipment. It is for use with systems covering a large territory.

For distributing information on current subjects of interest to the laboratory department, a form similar to that shown in Figure 112 will be found useful. In this way the superintendent or chief engineer may be sure that his assistants have important information. It will also assist the department in keeping up to date.

In Figure 113 is a suggested form for use when instruments are taken from the stock room or laboratory.

Chapter XVI

INSPECTION OF METER EQUIPMENT

Whenever checking is done in the field, the meters and instruments themselves should be very carefully inspected. A few of the important and general items to be considered are as follows:

1. All connections should be cleaned, properly made and not allowed to heat.

2. The meter itself should not be subjected to too high a temperature and especially great changes in temperature.

3. It should not be subjected to excessive vibration which will in time ruin the jewels upon which the movable coil or coils are mounted.

4. Instruments should be level and not tilted either backwards, forwards or sideways.

5. Instruments or meters should not be located in damp places and should be kept free from chemical fumes.

(Continued on page 139)

(NAME OF COMPANY)

INSTRUCTION SHEET FOR STATION WORK

In charge of.. Order No...

Assisted by.................. ....' Date..192....

Name of Co...Name of Station..

Address ....Type of Station..

How reached ....

Board at..Charge board to ....

Before starting work see Mr.. for passes, etc.

Address ....Ship meters by..

To ....In care of.. ....

Notify by Letter / Telephone / Telegraph — Form of Order..

Approx. time required for work...............................Work to start..

Apparatus has *not been tabulated. Numbers of meters start at..

Numbers of apparatus start at................Numbers of meter transformers start at.................

Artificial light will *not be required.

CALIBRATE	INSPECT
Indicating meters	Oil switches
Integrating "	Transformers
Graphic "	Generators
Current transformers	Motors
Potential "	Relays
Special Work as per Form.....................	Circuit breakers
	Arresters

Other work...

....

....

....

....

....

(For convenient use enlarge to size $8\frac{1}{2}'' \times 11''$)

*Cross out "not" if necessary.

Fig. 111

(NAME OF COMPANY)

INFORMATION SHEET

SHEET No. ....

To the .... Department Date, ... 192....

SUBJECT ....

The following appeared in—

Date of issue .... Page No. .... Edition ....

Give this information to .... Signed, ...

I have examined the above. Signed, ... Date, ... 192....

REMARKS: ....

....

....

....

(For Convenient Use Enlarge to $8\frac{1}{2}''$ x 11″)

Fig. 112

(NAME OF COMPANY)

REQUEST FOR INSTRUMENTS

ORDER No.................................

Name.. Date..................................192......

Address... Date Wanted...........................192......

.... Time Wanted............................192......

Ship Via.. Return by...

Address..

Instrument Wanted.. Model.....................................

Scale.......................... Amps............................ Volts.............................. Watts..........................

Frequency.......................... A. C. or D. C................................... Phase......................

TRANSFORMERS WANTED

No.	Type	Watts	E. P.	E. S.	I. P.	I. S.	Cycles

INSTRUMENTS LOANED	COST	DEPARTMENT	CONDITION

Remarks...

....

....

Date Shipped...192......

....Stand. Eng.

INSTRUMENTS RETURNED	CONDITION

Remarks...

....

....

Date Received...192......

Examined by......................................Stand. Eng.

(For Convenient Use Enlarge to Size $8\frac{1}{2}'' \times 11''$)

Fig. 113

6. They should not be located in the proximity of "stray fields," which come from magnetic apparatus or from conductors carrying heavy currents or from some forms of current transformers.

7. They should be kept perfectly clean and free from all foreign matter.

The above are a few items that can be very easily observed by the engineer making tests.

Chapter XVII

THE INSPECTION OF POWER PLANT EQUIPMENT

It is beyond the scope of this book to give details of the inspection of electrical equipment as used by the central station industry. However, it is believed that a few general notes on this subject will be of interest and assistance to a laboratory engineer who has charge of this branch of field work.

It requires a very careful man, thoroughly familiar with the design and operation of electrical apparatus, to become a competent inspector, and one that can be relied upon to see things for himself. Usually an outside party can do this work far better than a man who is constantly on the ground.

An oil switch cannot be properly inspected by looking at the tank containing the switch itself. The proper inspection means that the tank is removed, contacts and terminals examined, the oil tested to see that it has sufficient di-electric strength and in sufficient quantity to maintain the proper level.

For inspection purposes, power plant apparatus may be divided into two classes, rotating machinery and stationary equipment. The principal items to look for in rotating machinery cover proper lubrication, oil contents of bearings, oil rings, commutator and collector rings. Any undue heating or excessive vibration should be investigated and remedied. Bearings should be given special attention to see that the oil level is properly maintained, that oil rings are turning with the rotating shaft and that they are not worn sufficiently to require replacement. Good oil must also be available in the bearing and any dirt or foreign matter removed.

Inspection of stationary equipment such as transformers, switches, relays, etc., should be given careful attention. Oil used in transformers, switches, etc., for cooling and insulating purposes should be tested from time to time for its di-electric strength and condition.

The best way to carry out an inspection program is to call a meeting of all interested parties, having a representative from the operating and construction

departments present and then tabulating the equipment to be inspected, the items to be considered and the dates that inspection should be made. This work is more or less of a local problem and should not be neglected by the management.

Chapter XVIII

TESTING OF ELECTRICAL APPLIANCES

It is impossible for the electrical laboratory to thoroughly test electrical household appliances, due to the fact that actual working conditions are not reproduced. The laboratory can, however, determine the electrical qualities of the appliance and give its common sense judgment as to its good and bad points. Appliances must be looked upon from the customer's standpoint. The average laboratory engineer would never do the very things that the householder always does with electrical appliances. The only safe way is to take such appliances into your own home and abuse them exactly the same as they are abused when in the homes of the general public. However, there are a few items which should be carefully considered.

Electrical contact should be good and of sufficient area to prevent heating. The mechanical construction should be strong, any weak, flimsy appliances should be rejected. Avoid selecting any appliances from concerns that are not well established in business. This will avoid much embarrassment, in case repair parts cannot be easily obtained.

Chapter XIX

THE TESTING OF INDUSTRIAL PLANT EQUIPMENT

It is often necessary for the laboratory engineer to visit the plant of an industrial customer and conduct tests for determining power factor, demand, etc. These customers are generally non-technical and the use of electricity is only one of their many interests. For this reason non-technical language should be used and a clear explanation of facts should be given such parties.

As the subject of Industrial Testing is beyond the scope of this book, we have covered this subject in another book entitled "Electrical Testing in Industry." For engineers whose duties take them into industrial plants we will be glad to furnish a copy upon request.

Chapter XX

A FEW SUGGESTIONS ON THE CARE OF MEASURING INSTRUMENTS

While measuring instruments will stand a large amount of abuse, it is advisable to see that they have reasonable care in order that they may give continuous service with the highest degree of accuracy. We are listing below a few suggestions which are well worth while to consider by those who have anything to do with electrical instruments of any nature.

When an instrument is first received, a record should be made showing its number, model and other details. In case of loss at some later date, you can then notify us and we will automatically notify you in case it should ever be returned for repairs. Instruments should be listed on the inventory of the company and a careful record made for future use. This subject is taken up in detail in chapter entitled "Number System for Instruments and Meters."

When instruments are not in use they should be put away in some location that is free from dust, oil, heat, moisture and excessive vibrations. A bookcase or some covered partitions offer good storage space for instruments of any nature. When not in use, all instrument cases should be closed, and instruments provided with separate cases should be kept in their containers.

In making tests it is absolutely necessary that a proper place be selected for the different instruments as mentioned in a previous chapter. Instruments should not be placed upon the floor as they are liable to become injured and in that position they are extremely hard to read. When using instruments intermittently over any extended period of time, without disconnecting them, we recommend that they be properly covered with canvas or some water-proof covering.

When instruments are being carried for any distance leather carrying cases made to fit are recommended.

The packing of instruments for transportation should be given careful consideration and whenever they are shipped for any great distance they should be packed in excelsior after being carefully wrapped in paper. Excelsior absorbs the vibration better than any other packing material.

When instruments are carried on trains, trolley cars or in automobiles, it is not good practice to allow them to rest on the floor or on the seat unless it is provided with a cushion.

In time, excessive vibration is liable to damage any instrument. If no cushions are available it is better to carry them in the lap unless packed in a

box containing excelsior. Always lift the instruments and never allow them to slide on their rubber supports.

Instrument transformers having no movable parts can stand more vibration and do not require as much care as pivoted coil instruments.

The covers on the larger size Weston Portable Precision Instruments can be removed. This is very convenient when a number of instruments are used in making some particular test. Be sure that these covers have proper protection when not in use and that they are put back on the proper instrument when the test is completed.

We suggest polishing wooden meter cases occasionally with some good furniture polish in order to keep them in first-class condition. The better the appearance of an instrument, the more care is applied in handling and using it.

If a meter becomes damaged or needs attention in any way, ship it direct to the Weston Electrical Instrument Corp., Newark, N. J., with transportation charges prepaid. Protect the glass over the scale to avoid breakage; place your name and address inside the instrument case, and also write a letter to the corporation, giving the number and model of the instrument, how shipped and the work you wish done. Be sure to keep a copy of your letter and the number and model of your meter.

Chapter XXI

PROTECTION AGAINST PERSONAL INJURY

It would be impossible to list all the different things which might happen to those whose duty requires them to handle electricity, and for this reason we are only making a few very general but important suggestions. As a matter of fact, injury from mechanical means is far more frequent than from the electrical current itself. For the benefit of all and especially the engineer himself, we make the following suggestions:

1. In conducting electrical test work, proper planning and proper accessory equipment will practically eliminate the possibility of shock.

2. It is recommended that all instruments and apparatus be connected up and checked before the final connections to the circuit are made. This will avoid the necessity of handling a number of live wires.

3. If possible, use only one hand, and when doing so it is very essential that no other portion of the body comes in contact with a live conductor or ground.

4. If there is any question about the insulation of the floor or platform it is better to stand on some insulating material such as a heavy piece of DRY wood. Be extremely careful of cement floors, which often appear dry on the surface but will cause a shock to any person who enters with damp shoes.

5. Rubber gloves are recommended provided they have been tested previous to use, but the engineer must also be very careful to prevent these gloves becoming punctured at any time by "burs" or the ends of small wires.

6. After a severe thunder storm be extremely careful in handling any apparatus that may have become damaged on such an occasion. Current and potential transformers should be handled very carefully, especially if no ground connection is available.

7. MOVE CAREFULLY AND THINK BEFORE YOU ACT.

APPENDIX

Chapter XXII

The following useful tables appear in this chapter:

1. Electrical Formulae for Determining Horse-Power, K. V. A., Kilowatts and Amperes.
2. Allowable Carrying Capacities of Copper Wires.
3. Synchronous Speeds of Alternating Current Generators and Motors.
4. Current Required to Fuse Wires.
5. Carrying Capacity of Iron Wire.

ELECTRICAL FORMULAE FOR DETERMINING HORSE-POWER, KV-A, KILOWATTS AND AMPERES

TABLE 1

To Find	Direct Current	Alternating Current		
		Single-Phase	Three-Phase	Two-Phase, Four Wire
* Amperes when Kilowatts are known	$\frac{Kw \times 1000}{E}$	$\frac{Kw \times 1000}{E \times P.F.}$	$\frac{Kw \times 1000}{1.73 \times E \times P.F.}$	$\frac{Kw \times 1000}{2 \times E \times P.F.}$
Amperes when KV-A is known		$\frac{KV\text{-}A \times 1000}{E}$	$\frac{KV\text{-}A \times 1000}{1.73 \times E}$	$\frac{KV\text{-}A \times 1000}{2 \times E}$
Amperes when Horse-power is known	$\frac{H.P. \times 746}{E \times Eff.}$	$\frac{H.P. \times 746}{E \times Eff. \times P.F.}$	$\frac{H.P. \times 746}{1.73 \times E \times Eff. \times P.F.}$	$\frac{H.P. \times 746}{2 \times E \times Eff. \times P.F.}$
Horse-power (Output)	$\frac{I \times E \times Eff.}{746}$	$\frac{I \times E \times Eff. \times P.F.}{746}$	$\frac{I \times E \times 1.73 \times Eff. \times P.F.}{746}$	$\frac{I \times E \times 2 \times Eff. \times P.F.}{746}$
Kilowatts	$\frac{I \times E}{1000}$	$\frac{I \times E \times P.F.}{1000}$	$\frac{I \times E \times 1.73 \times P.F.}{1000}$	$\frac{I \times E \times 2 \times P.F.}{1000}$
KV-A		$\frac{I \times E}{1000}$	$\frac{I \times E \times 1.73}{1000}$	$\frac{I \times E \times 2}{1000}$

I equals Amperes; E equals Volts; Eff. equals Efficiency; P.F. equals Power Factor; Kw equals Kilowatts; KV-A equals Kilovolt-Amperes; H.P. equals Horse-power.

*For three-wire, two-phase circuits the current in the common conductor is 1.41 times that in either of the other two conductors on a balanced system.

ALLOWABLE CARRYING CAPACITIES OF COPPER WIRES

TABLE 2

B. & S. Gauge	Area in Circular Mils	Rubber Insulation Amperes	Other Insulation Amperes
18	1,624	3	5
16	2,583	6	10
14	4,107	15	20
12	6,530	20	25
10	10,380	25	30
8	16,510	35	50
6	26,250	50	70
5	33,100	55	80
4	41,740	70	90
3	52,630	80	100
2	66,370	90	125
1	83,690	100	150
0	105,500	125	200
00	133,100	150	225
000	167,800	175	275
--------	200,000	200	300
0000	211,600	225	325
--------	250,000	250	350
--------	300,000	275	400
--------	350,000	300	450
--------	400,000	325	500
--------	500,000	400	600
--------	600,000	450	680
--------	700,000	500	760
--------	800,000	550	840
--------	900,000	600	920
--------	1,000,000	650	1,000

The above table does not take into consideration the "volts lost" or "drop of potential," but covers heating only.

Insulated aluminum conductors will carry 84% of the current carried by copper wire without overheating.

APPROXIMATE SYNCHRONOUS SPEEDS—ALTERNATING CURRENT GENERATORS AND MOTORS

TABLE 3

Number of Poles	Revolutions Per Minute When Frequency is				
	25 Cycles	30 Cycles	40 Cycles	50 Cycles	60 Cycles
2	1,500	1,800	2,400	3,000	3,600
4	750	900	1,200	1,500	1,800
6	500	600	800	1,000	1,200
8	375	450	600	750	900
10	300	360	480	600	720
12	250	300	400	500	600
14	214	257	343	428	514
16	188	225	300	375	450
18	167	200	267	333	400
20	150	180	240	300	360
22	136	164	217	273	327
24	125	150	200	250	300
26	115	138	185	231	280
28	107	128	171	214	257
30	100	120	160	200	240
32	94	113	150	188	225
36	83	100	133	166	200
44	79	82	109	136	164
48	63	75	100	125	150
54	56	66	90	111	133
60	50	60	80	100	120
68	44	53	71	88	106
72	42	50	67	83	100
96	31	38	50	64	75
100	30	36	48	60	72

$$\text{Frequency} = \frac{\text{Poles} \times \text{R.P.M.}}{120}$$

CURRENT REQUIRED TO FUSE WIRES

TABLE 4

B. & S. Gauge	Copper Amperes	Iron Amperes	B. & S. Gauge	Copper Amperes	Iron Amperes
10	333.	101.	26	20.6	6.22
11	284.	86.	27	17.7	5.36
12	235.	71.2	28	14.7	4.45
13	200.	63.	29	12.5	3.79
14	166.	50.2	30	10.25	3.11
15	139.	42.1	31	8.75	2.65
16	117.	35.5	32	7.26	2.2
17	99.	32.6	33	6.19	1.88
18	82.8	25.1	34	5.12	1.55
19	66.7	20.2	35	4.37	1.33
20	58.3	17.7	36	3.62	1.09
21	49.3	14.9	37	3.08	.93
22	41.2	12.5	38	2.55	.77
23	34.5	10.9	39	2.20	.67
24	28.9	8.76	40	1.86	.56
25	24.6	7.46			

CARRYING CAPACITY OF IRON WIRE

TABLE 5

B. & S. Gauge	Safe Current in Wood Frame	Safe Current in Iron Frame	Safe Current for One Minute	Number of Feet per Ohm
8	17.4	20.3	43.6	250.
9	14.6	17.1	36.6	173.
10	12.3	14.3	30.8	137.
11	10.3	12.	25.8	108.
12	8.7	10.	21.7	86.4
13	7.3	8.5	18.3	68.4
14	6.1	7.	15.3	54.3
15	5.1	6.	12.8	43.1
16	4.3	5.	10.8	34.1
17	3.6	4.2	9.1	27.1
18	3.	3.5	7.6	24.3
19	2.52	2.9	6.3	16.5
20	2.17	2.5	5.4	13.5
21	1.82	2.1	4.5	10.7
22	1.53	1.77	3.8	8.49
23	1.28	1.49	3.2	6.73
24	1.08	1.20	2.3	5.34

Chapter XXIII

TABULATION SHEETS

This chapter contains four tabulation sheets, which will be found very useful for recording the necessary data when checking INDICATING METERS, INTEGRATING METERS, CURRENT TRANSFORMERS and POTENTIAL TRANSFORMERS.

These tabulation sheets are illustrated on the following pages, 149 to 151. They have been reduced in size so as to confine them to the length of a single page. For practical use they should be expanded to a size of about 17 x 11 inches, which will make them large enough to readily record the information necessary without undue crowding.

Name Of Company .... **INDICATING METERS** Tabulated By .... Date Tabulated .... 192... Order No. ....

Station .... Checked By .... Date Checked .... 192.. Sheet No. ....

Inst. No.	Meter	Scale	Board	Panel	Make	Makers No.	Serial or Model No.	Type	Form	Amps.	Volts	Cycles	Phase	Wire	Current Winding	Potential Winding	Seal		Potential T. No.	Current T. No.	Use	Repairs	Temp.	Vibration	Accuracy Found	Accuracy Left	Check Sheet No.
																	Found	Left									

INSTRUMENTS REQUIRED FOR CALIBRATING METERS LISTED ON OTHER SIDE OF THIS SHEET

Ammeters .... Scales ....

Voltmeters .... " ....

Wattmeter .... " ....Phase

Frequency .... " ....

Power Factor .... " ....

Phase Shifter ....

Rotating Stds. ....

Potential Trans. .... Ratios ....

Current " .... " ....

Jumpers ....

Comparator Voltmeter ....

Test Table .... Shunts ....

Meter Clips ....

Remarks ....

....

Sig. ....

(For convenient use enlarge sheet to size 11" x 17")

To be printed on the reverse side of this tabulation sheet

NAME OF COMPANY............................ STATION............................

INTERGRATING METERS

TABULATED BY............ DATE TABULATED ....192... ORDER NO...........
CHECKED BY............ DATE CHECKED.....................192... SHEET NO...........

METER NO.	BOARD	PANEL	MAKE	MAKERS NO.	STYLE NO.	TYPE	FORM	AMPS.	VOLTS	CYCLES	PHASE	WIRE	CONSTANT	TERMS OF CONSTANT	READING	RATCHETT	DIALS	DIAL MULT.	LEVEL	CURRENT WINDING	POTENTIAL WIND NG	SEAL FOUND	SEAL LEFT	POTENTIAL T. NO.	CURRENT T. NO.	USE	REPAIRS	TEMP.	VIBRATION	ACCURACY FOUND	ACCURACY LEFT	CHECK SHEET NO.

INSTRUMENTS REQUIRED FOR CALIBRATION OF INSTRUMENTS AND METERS IN THE STATION

Ammeters .... Scales..
Voltmeters .... " ....
Wattmeter .... " ....Phase
Frequency .... " ....
Power Factor.. " ....
Phase Shifter ....
Rotating Stds..
Potential Trans. .... Ratios..
Current " .... " ....
Jumpers ....
Comparator Voltmeter ....
Test Table .... Shunts ....
Meter Clips ....
Remarks ....
....
Sig..

(For convenient use enlarge sheet to size 11" x 17")

To be printed on the reverse
side of this tabulation sheet

Name Of Company.................................... **CURRENT TRANSFORMERS** Tabulated By.......... Date Tabulated.................192... Order No..........

Station.. Checked By............ Date Checked..................192... Sheet No..........

Trans. No.	Operates Meter No.	Ratio	Board	Rear of Panel No.	Make	Makers No.	Style No.	Spec. No.	Type	Form	Amps.	Volts	Cycles	K.V.A.	Voltage of Circuit	Spec Ratings Amps.	Mins.	Secondary Load	Operates with Trans. No.	Ground	Accuracy Found	Accuracy Left	Check Sheet No.

Name Of Company.................................... **POTENTIAL TRANSFORMERS** Tabulated By.......... Date Tabulated.................192... Order No..........

Station.. Checked By............ Date Checked..................192... Sheet No..........

Trans. No.	Operates Meter No.	Ratio	Board	Rear of Panel No.	Make	Makers No.	Style No.	Spec. No.	Type	Form	Fuses	Cycles	Watts	Voltage of Circuit	Primary Volts	Secondary Volts	Secondary Loads	Operates with Trans. No.	Ground	Accuracy Found	Accuracy Left	Check Sheet No.

(For convenient use enlarge these tabulation sheets to size 11" x 17")

GENERAL INDEX